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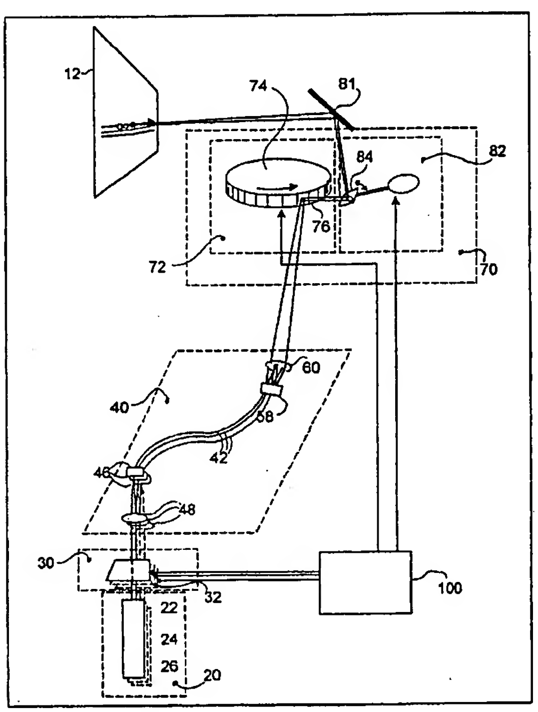
(54) Title: LASER PROJECTION SYSTEM



(57) Abstract: A laser projection system suitable for use in commercial motion picture theaters and other large scren venues, including home theater, uses optical fibers to project modulated laser beams for simultaneously raster scanning multiple lines on the screen. The emitting ends of the optical fibers are arranged in an array such that red, green and blue spots are simultaneously scanned onto the screen in multiple lines spaced one or more than one scan line apart. The use of optical fibers enables the scanning of small, high resolution spots on the screen, and permits convenient packaging and replacement, upgrading or modification of the system components. The simultaneous raster scanning of multiple lines enables higher resolution, brightness, and frame rates with available economical components. Alternate embodiments are disclosed to illustrate the flexibility of the system for different optical fiber output head configurations and for different types, sizes, and arrangements of laser, modulation, and scanning components.

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LASER PROJECTION SYSTEM

FIELD OF THE INVENTION

This invention relates generally to high resolution video projection systems using visible laser beams as a possible light source, and more particularly to systems for projecting large color motion picture or video images onto a screen suitable for viewing at home, in a theater, at a concert, or other presentation or gathering.

BACKGROUND OF THE INVENTION

Large motion color images, such as displayed in movie theaters, are formed by projecting light through individual film frames illuminating a full screen, with frames succeeding one another at 20 to 30 times a second. Movie projection utilizing an electronic (usually digital) image source (termed "video" herein) is a desirable alternative to film, assuming such an image can be projected with sufficient brightness, resolution, color balance, registration, and lack of motion artifacts to equal or exceed the capabilities of film.

The typical prior art laser projection systems used complicated lens and mirror systems to combine modulated colored beams into a composite beam to be scanned, and additional optics to scan and focus the beams onto a screen. These optics sap much of the power of the laser beams, making laser projection images substantially less bright than conventional film images. Further, because certain wavelengths, especially blue, have been difficult to produce at adequate power levels with lasers, brightness and color balance have been inadequate for large screen video applications.

Laser projection systems used complex optics and scanning systems that tended to cause color separation and image artifacts. Perhaps the most significant problem, however, with prior laser projections systems in comparison with film projection technology is the lack of sufficient resolution. Attempts to increase resolution only exacerbate the problems noted above. In order to effectively compete with or displace

film projection, it is widely believed that laser projection systems must be capable of resolutions approaching 1900 by 1100 fully resolved pixels, or roughly the maximum resolution of the newly established High Definition Television (HDTV) standard of 1920x1080p.

Standard television quality resolution rarely exceeds 525 horizontal lines repeated 30 times a second. For television to achieve this resolution, 525 horizontal lines of analog image data are scanned, roughly comparable to a digital pixel array of 525x525 pixels. Thus, television quality video would require more than 945,000 lines per minute. A 25 facet polygon mirror writing one line with each facet would require a rotation of more than 37,500 rpm. If one were to attempt scanning 1920 x 1080 HDTV or better resolution video with prior art projectors, the greater than threefold increase in horizontal resolution would mandate a larger facet size, although the increased number of lines per frame would require either an increase in the number of facets or substantially increased polygon mirror rotational speeds. For example, a 25 facet polygon mirror would need facets more than three times greater in width resulting in a polygon more than three times greater in diameter. For HDTV 1920x1080p resolution at a full frame rate of 60 frames per second, this polygon of much larger facet widths would have to scan more than 3.8 million lines per minute, or achieve a rotational speed of more than 150,000 rpm. A polygon mirror assembly capable of these facet rates would be structurally difficult to manufacture and operate, and extremely expensive. Due to centrifugal force limitations one cannot increase the number of facets per second simply by increasing the number of facets of the same size without reducing facet size on the polygon.

The limitations of modulation technology pose additional problems. Each laser beam of the three primary colors must be modulated to produce a different color intensity for each pixel being scanned. For standard television resolution, more than 250,000 modulations must occur for each frame for each color or laser, or a total of 7.5 million modulations per second for 30

full frames per second. For high resolution, at 1920x1080p, more than 2 million modulations must occur for each color or laser to scan each frame, or a total of at least 120 million modulations per second per color for 60 frames per second. For desired non-interlaced (progressive) imagery having even greater resolution, such as 3000x2000 pixels, the rate is above 360 million modulations per second. Current modulation technology as used in prior art laser projectors is not capable of modulating the laser beams, especially powerful laser beams, at a sufficient rate to enable the generation of the number of discreet pixels required for even film-quality digital resolution.

There are other inadequacies in the existing technology that are not addressed in detail here, that impose additional challenges, including complexity of optics, brightness, resolution, contrast and image stability.

SUMMARY OF THE INVENTION

Nothing in the prior art has provided a laser projection system that combines sufficient resolution, brightness and color for large screen projection, such as in a movie theater, to rival or exceed that of film. Our invention uses a novel approach to scanning laser beams onto a screen that facilitates the use of many simple, proven laser projection components to produce a bright, color saturated, high resolution large screen image at a reasonable cost.

Before further summarizing our invention, it is necessary to define and place in context several terms and concepts to be utilized in describing the projection of laser beams on a screen. As noted in greater detail in the Detailed Description herein, video images projected by our preferred system according to our invention are formed by raster scanning. Raster scanning, the process used by our invention as well as television and many (but not all) other video display techniques, is a process where a flying spot of illumination scans across the image surface or viewing surface or screen forming an image line, repeating the process lower, until scanned lines fill the entire viewing surface. A completely scanned image is called a "frame".

Continuous raster scanning is a process of scanning a pre-determined pattern of lines within a display space, wherein the horizontal scanning motion is continuous during a line or scan pass (defined raster herein), and the traverse is continuous or nearly continuous within a frame or subframe (defined below). The lines will be parallel in most instances.

The locations and values of the separate elements of a frame of video data are referred to as "pixels" herein. The manifestation of the modulated laser beam on a screen that is visually apparent to the viewer is referred to as a "spot", that is, the visible illumination resulting from reflection of laser beam from the screen shall be considered a "spot". A location on the screen corresponding to the same relative position of a particular pixel in the video data is referred to herein as a "dot". A "line" shall herein be considered to refer to the horizontal (in most cases) row of individual dots. A "frame" shall be regarded as a series of contiguous lines forming a complete image. Frames are repeated many times per second in all video images. A "subframe" shall be regarded as a group of lines in which the drawing of another group of lines in different locations at a later time is required to draw a complete desired image or frame. An example is the two subframes of lines required with typical interlaced scanning to form a complete frame, such as in standard television.

We define "refresh rate" as in the television industry standard where the refresh rate refers to the number of sweeps or scans down the screen, in that case 60 per second, although some define the refresh rate as the rate at which all of the information is completely updated, which in that case would be 30 times per second.

In the National Television Standards Committee (NTSC) television system used in the United States, one-half frame is scanned about every 1/60th second, with odd lines scanned in one subframe and even lines scanned in the next (termed "interlaced scanning" herein), thereby effectively repeating or updating each full frame 30 times a second. In many computer monitors, the

image is progressively scanned, that is all lines of each frame are scanned in one pass, typically at a refresh rate of 60 or more times per second. The size of the pixel arrays range from the equivalent of 525x525i, (where "i" refers to the interlaced method), to 1920x1080p (where "p" refers to the progressive method)in the most demanding high definition television (HDTV) resolution standard. Thus, between 15,000 and 65,000 horizontal lines, or between 8.3 and 124.0 million pixels, are scanned each second at a refresh rate of 60 frames per second.

A laser projection system according to our invention preferably utilizes optical fibers to transmit modulated laser beams in the three primary colors, red, blue and green, from laser sources. This effectively preserves the point source characteristics of narrow focus beams exiting from the laser sources which can be directed through the scanning component to the screen without complex and expensive optics used in prior art systems. The use of optical fibers for laser beam transmission also facilitates packaging of the system. Further, problems with divergence and degradation of laser beams transmitted through mirrors and other optics for scanning are reduced by the use of optical fibers. "Primary colors" shall be understood to mean colors of appropriate laser beam wavelengths, such that when combined at a dot location on a screen at the appropriate intensity, the color resulting from such combination will have the color characteristics desired for most colors. We also contemplate the use of a single color for monochrome projection, or two colors, or more than three colors in combination to enhance the range of available composite colors, to accomplish the objectives of different projection systems.

A laser projection system according to our invention may also use the beams emitted from the emitting ends of two or more optical fibers, with each fiber transmitting one of the primary colors (red, green, blue), to draw a line of spots. Instead of combining the three primary color beams before transmitting the beams to the scanning apparatus as in prior systems, one aspect of our invention permits the individually modulated laser beams

of each color to form spots that are transmitted at different times to strike a particular dot location on the screen and create a composite color having a value corresponding to the pixel data color values. The use of the emitting ends of the optical fibers to direct the beams to the scanning apparatus, with the reordering or time combining of the actual illumination of each dot location with each color beam avoids the complicated optics of prior systems which combined the various beams before projection onto a dot location. This reordering is illustrated in the Detailed Description.

In most instances, the color required for a specific dot location on the screen will be produced by illuminating that dot location with some combination of appropriately modulated red, green and blue spots. In a preferred laser projection system according to our invention, this requires appropriate delays in timing of beam activation and modulation, so that the appropriately modulated beam is activated at the appropriate time the beam is positioned to produce a spot at the specified dot location. Further examples of this reordering, which may also be characterized as time delaying, time combining or time shifting, as well as the presentation of lines, presentation of colors and/or rearranging of the sequence in which the video data is originally input, are more specifically described in the Detailed Description section hereof.

It should be understood that the term "horizontal" to describe the scanning of lines and the term "vertical" to describe the adjustment of the position of horizontal lines in the frame, are for convenient reference only. Those familiar with raster scanning in televisions and CRTs such as computer monitors, will understand that this illustrative system could be rotated 90°, so that lines would be scanned vertically and transverse adjustments in the frame made horizontally. Further, scanning diagonally, and in a spiral from the center of the frame, or in from the outer edge, have been known in other applications. Given the flexibility afforded by our invention in accommodating various scanning systems and laser and modulator

configurations, numerous scanning regimes for front and rear projection could be utilized to effect. In some cases, we use the terms "sweeping or scanning or line direction" or "swept or scanned" to more generically describe the direction in which lines are scanned along desired paths on the screen or viewing surface, analogous to the horizontal scans described at length herein, without restricting the direction of the sweeping of the paths to any particular orientation. In such cases, we may also use the term "frame or transverse direction" or "moved" or "adjusted" to more generically describe the transverse direction in which the position of the lines or desired sweep or scan paths are offset, analogous to the vertical scans or adjustments also described at length herein, without restricting that direction to any particular orientation, or indeed any orientation.

Our innovation using optical fibers frees large venue laser video projection from constraints on the method of modulation and on laser sources. Indeed, our system can be easily adapted to a variety of suitable laser sources or modulation components. Further, within our invention, various techniques of combining or splitting laser beams after they have been inserted into optical fibers can be advantageously employed.

A laser projection system according to our invention further preferably utilizes a plurality of point sources, such as fiber emitting ends arranged in an array, to project a pattern of spots on a screen. For convenient reference, we prefer to call the horizontally aligned fiber emitting ends used to draw a line of spots on the screen a "row" of fiber emitting ends. As described below, a row may also comprise one or more beams or spots of a pattern of beams or spots projected on a screen. Such array of fiber emitting ends in our preferred embodiment may be effectively arranged in rows of emitting ends spaced apart vertically to project and scan a two dimensional pattern of spots along more than one horizontal line at a time. Such multiple line scanning according to our invention provides a method of achieving high resolution with current scanning, modulation and

laser components otherwise not capable of producing high resolution video images, as described above.

Thus, our system realizes several advantages of scanning more than one line per horizontal or scan. One advantage includes an ability to use simpler, less expensive scanning components, such as a polygon mirror having a more common number of facets and operating at a conventional rotational speed for high resolution raster scanning. For example, for 1920x1080p or better quality resolution, a 25 facet polygon mirror scanning one line per facet at a full frame rate of 60 frames per second would have to scan more than 3.8 million lines per minute at more than 150,000 rpm. Scanning four lines per facet would reduce that rotational speed by a factor of four, to about 37,500 rpm, which is within manageable limits for existing polygon mirror technology.

Another advantage is the reduction in modulation speed achieved by individually modulating, in the foregoing example, four rows of laser beams and scanning them simultaneously. The modulation of the individual beams is thus reduced by a factor of four at the desired resolution. Without our invention, 1920 x 1080p requires modulation at 120 million modulations per second to scan each pixel or spot at a rate of one line at a time, whereas scanning four lines at a time reduces this requirement to approximately 30 million modulations per second, again within the capabilities of current acousto-optic or other existing modulation technology.

Our invention helps to ameliorate other problems associated with the laser power requirements for large screen projection at acceptable levels of brightness. Laser beams of large screen projection systems must have sufficient power to illuminate each dot location on a screen with a minimum desired illumination.

The viewer perceives the light on the screen produced by a single laser beam of a prior system at one power as equal to that produced by multiple laser beams having the same power in the aggregate. However, the modulator for the prior system must handle the total power for the single beam, whereas for a multi-

line scanning system according to our invention such power is divided among the multiple beams and modulators. The high power laser beam required for such prior laser projection systems produces a power density in the modulator crystal that current acousto-optic modulators simply cannot handle. The division of the modulation tasks among multiple modulators in accordance with our invention, such as four times as many modulators with our preferred embodiment, reduces the power load that must be handled by each modulator by that multiple, or by a factor of four with our preferred embodiment, more within the capacity of current acousto-optic modulators.

The use of multiple line scanning facilitates the use of optical fibers. Even if, hypothetically, a prior designer of a laser projection system were to attempt to use optical fibers, as taught by our invention, to transmit the laser beams to the scanning components, the high power density where the light enters and leaves the fiber would damage the fiber. As described for modulation requirements, dividing the laser power between multiple fibers to transmit the same effective power to the screen as prior art systems reduces the power density each individual fiber must handle, permitting the use of currently available optical fibers in a system according to our invention.

The use of optical fibers in our preferred system is enabling of multi-line scanning. If multi-line scanning in accordance with our invention were attempted without using fibers, the complexity and expense of the necessary optics to perform such scanning would be multiplied many times. Additionally, in the absence of optical fibers used in accordance with our invention, the problems associated with accurately positioning multiple separate beams or composite beams in a vertical spacing suitable for multi-line scanning with prior technology are for all practical purposes insurmountable.

Further, within our invention, the use of optical fibers also enables the use of various techniques of combining and splitting laser beams that have already been inserted into fibers (hereinafter "fiber-based beam coupling"). This allows us to

efficiently combine beams of various primary colors to form a composite beam as in prior art projectors and, as will be discussed at length hereinafter, it also allows us unprecedented flexibility in the choice of laser sources and modulators, with the attendant advantages of favorable economics, size, availability and beam characteristics. This is especially important when one considers that combining the beams of more than two small lasers of the same wavelength into one coherent diffraction limited beam is not feasible in laser projectors without our invention.

Yet another advantage of multiple line scanning is the ease of using multiple lasers for each color. In some cases, it may be more economical or otherwise more effective to use several small lasers per color, such as by using one laser per color per row or by using several emitting ends for a given color per row each with its own laser, than it is to use one large laser for each color where the output is split, or divided, among the several rows, even though the use of fiber makes such splitting far more efficient than in prior art laser projectors. Thus, our invention uniquely allows several approaches to using multiple lower power laser beam sources in a raster scanning environment.

A major advantage of our invention is the ability to use a single lens to direct the beams from the array of fiber emitting ends through the scanning components and thence on the screen. This avoids the use of complicated optical systems common to prior laser projection systems, such as disclosed in Linden, US 5,136,426. Our preferred use of a single lens helps to effect the greatest possible resolution of the laser beam on the screen by producing the smallest feasible spot and by avoiding the degradation in beam quality that results from multiple optical elements in a complex optical path. The resulting increased optical efficiency also permits lower power lasers, because more of the laser power reaches the screen than with complex optical arrays. The simple achromat lens preferred for our preferred system according to our invention is significantly less expensive than the multiple, and typically more complex, lenses and mirrors

used in prior laser projection systems. Lastly, the use of a simple lens simplifies manufacture, setup, repair and adjustment of the preferred laser projection system.

The foregoing advantages of the present invention are realized in the embodiments described by way of example and not necessarily by way of limitation hereinafter, which disclose laser projection systems suitable for use in a large screen commercial motion picture theater and other large or small screen venues using video and having levels of brightness, resolution and color balance exceeding that of film.

Additional advantages and novel features of the invention will be set forth in the description which follows, and will become apparent to those skilled in the art upon examination of the following more detailed description and drawings in which like elements of the invention are similarly numbered throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a laser projection system of a first embodiment of our invention.

FIG. 2 is a diagram of a theater in which the system of FIG. 1 may be employed.

FIG. 3 is a schematic representation of the lens used to insert the modulated beam into the fiber in the spot projection section of the system shown in FIG. 1.

FIG. 4 is a diagram of a theater in which the system of FIG. 1 may be employed in rear projection.

FIG. 5 is a diagram of the array of fiber emitting ends in an output head of the system of FIG. 1.

FIG. 5S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 5.

FIG. 6 is a diagram showing elements of the laser, spot projection and modulation sections where the colored beams for each of several lines are combined after insertion into fiber and modulation using wavelength division multiplexing or other fiber-based beam coupling.

FIG. 7 is a diagram of an alternate output head for use in the systems of Fig.1 and Fig.6, according to Example 21, and having four row by one emitting end per row array arranged on a slant.

FIG. 7S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 7.

FIG. 8 is a diagram of a four row by six emitting ends per row array further described in connection with Example 12.

FIG. 8S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 8.

FIG. 9 is a schematic diagram of the scanning section of our preferred system of FIG. 1.

FIG. 10 is a schematic diagram of an alternate scanning section wherein the output lens is focussed near to the polygon mirror facet and a complex relay lens focusses the pattern of beams onto the screen.

FIG. 11 is a schematic diagram of a system similar to that shown in FIG. 9, except that the aggregate beam is first directed to the galvanometer.

FIG. 12 is a schematic diagram similar to FIG. 9 except that there is a negative Barlow lens between the polygon and the galvanometer that widens the fan of the emitted beams on the screen.

FIGs. 13A through 13J are time sequence diagrams illustrating the time shifting of spots of each primary color in a row of a pattern of spots shown in FIG. 5S to form composite spots at dot locations of a line of a frame.

FIGs. 14A through 14E are time sequence diagrams illustrating the out-of-order illumination of lines for scan passes at the beginning of the frame with vertically spaced rows of the spot pattern shown in FIG. 5S, showing blanking of rows of spots not within the frame.

FIGs. 15A through 15E are time sequence diagrams illustrating the out-of-order illumination of lines for scan passes at the end of the frame with vertically spaced rows of the

spot pattern shown in FIG. 5S, showing blanking of rows of spots not within the frame.

FIG. 16 is a diagram of the beam paths from the emitting ends to the facet of the polygon mirror.

FIG. 17 is a schematic diagram of the laser section of the laser projection system of FIG. 1 having one laser of each color.

FIG. 18 is a schematic diagram of an alternate laser section for use in a system similar to that shown in FIG. 1 having one red laser, one green laser and sixteen blue lasers.

FIG. 19 is a schematic diagram of another laser section for use in a system similar to that shown in FIG. 1 having four lasers of each color.

FIG. 20 is a schematic diagram of elements of the laser, modulation and spot projection sections where, for example, several lasers of slightly different red wavelengths are combined after insertion into fiber and modulation using wavelength division multiplexing techniques.

FIG. 21 is a schematic diagram of elements of the laser, modulation and spot projection sections where multiple smaller lasers are combined after insertion into fiber and modulation using other fiber-based beam coupling.

FIG. 22 is a schematic diagram of elements of the laser, modulation and spot projection sections where multiple smaller lasers are combined after insertion into fiber, but before modulation, using polarizing combiners.

FIG. 23 is a schematic diagram of elements of the laser, modulation and spot projection sections where many modulators are used for the same color for a given line, in which the modulators are preferably fiber-based modulators.

FIG. 24 is a schematic diagram of elements of the laser, modulation and spot projection sections where combining of beams after insertion into fiber occurs for one color before modulation, and, in a second case, after modulation.

FIG. 25 is a schematic diagram of elements of the laser, modulation and spot projection sections for use with the system of FIG. 1 and the four row by one emitting end per row output

head according to Example 21 showing several separate combinations and divisions of beams after insertion into fiber.

FIG. 26 is a block diagram of a controller section of the laser projection system of FIG. 1.

FIG. 27 is a diagram of a 4 row by 3 emitting end per row array of an alternate output head for use in the system of FIG. 1, having fibers of adjacent rows offset for a reduced effective row spacing, referred to as a "log" array.

FIG. 27S is a diagram of the pattern of spots projected on a screen using the "log" array shown in FIG. 27.

FIGs. 28A through 28H are time sequence diagrams for Example 1, illustrating line reordering for the 4x3 spot pattern of FIG. 27S having an effective row spacing of three lines and vertical adjustment between scan passes of four lines.

FIGs. 29A through 29D are time sequence diagrams for Example 2, illustrating the ineffective line reordering for a 4x3 spot pattern similar to FIG. 27S having an effective row spacing of four lines and a vertical adjustment between scan passes of four lines.

FIGs. 30A through 30D are time sequence diagrams for Example 3, illustrating the ineffective line reordering for a 4X3 spot pattern similar to FIG. 27S having an effective row spacing of four lines and a vertical adjustment between scan passes of five lines.

FIGs. 31A through 31F are time sequence diagrams for FIGs. 24A through 24D and 25A through 25D, illustrating the time shifting of spots of each primary color in a row of a pattern of spots of FIG. 27S to form a composite spot at each dot location of a line of a frame.

FIGs. 32A through 32H are time sequence diagrams for Example 4, illustrating line reordering for a 4x3 spot pattern similar to that of FIG. 27S having an effective row spacing of 49 lines and a vertical adjustment between scan passes of four lines.

FIG. 33 is a diagram for Example 5, showing a 3 row by 3 emitting end per row array of an alternate output head for use in the system of FIG. 1.

FIG. 33S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 33.

FIGs. 34A through 34H are time sequence diagrams for Example 5, illustrating line reordering for a 3x3 spot pattern of FIG. 33S having an effective row spacing of 4 lines and a vertical adjustment between scan passes of 3 lines.

FIG. 35 is a diagram for Example 6, showing a 2 row by 3 emitting end per row array of an alternate output head for use in the system of FIG. 1.

FIG. 35S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 35.

FIGs. 36A through 36H are time sequence diagrams for Example 6, illustrating line reordering for a 2x3 spot pattern similar to that of FIG. 35S having an effective row spacing of 9 lines and a vertical adjustment between scan passes of 2 lines.

FIGs. 37A through 37H are time sequence diagrams for Example 7, illustrating line reordering for a 4x3 spot pattern similar to that of FIG. 27S having an effective row spacing of 11 lines between RowA and RowB, 10 lines between RowB and RowC, and 13 lines between RowC and RowD, and a vertical adjustment between scan passes of 4 lines.

FIG. 38 is a diagram of a 5 row by 3 emitting end per row array of an alternate output head for use in the system of FIG. 1 according to Example 8.

FIG. 38S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 38.

FIGs. 39A through 39J are time sequence diagrams for Example 8, illustrating line reordering for a 5x3 spot pattern of FIG. 38S having an effective row spacing of 6 lines and a vertical adjustment between scan passes of 5 lines.

FIG. 40 is a diagram of a 4 row by 6 emitting ends per row array of an alternate output head for use in the system of FIG. 1 according to Example 9.

FIG. 40S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 40.

FIGs. 41A through 41F are time sequence diagrams for Example 9, illustrating the time shifting of spots of each primary color in RowA through RowD of a pattern of spots shown in FIG. 40S to form composite spots at dot locations at the beginning of scan pass s3.

FIGs. 42A through 42F are time sequence diagrams for Example 9, illustrating the time shifting of spots of each primary color in RowA through RowD of a pattern of spots shown in FIG. 40S to form composite spots at dot locations at the end of scan pass s3.

FIG. 43 is a diagram of the pattern of spots and the resulting lines of each color in each line projected on a screen by a 4 row by 3 emitting ends per row array of an alternate output head for use in the system of FIG. 1 according to Example 10.

FIG. 44 is a diagram of the pattern of spots projected by a 4 row by 3 emitting ends per row array of another output head for use in the system of FIG. 1 according to Example 11, where the emitting ends, and therefore the pattern of spots, within each row are not uniformly horizontally spaced apart.

FIGs. 45A through 45F are time sequence diagrams for Example 11, illustrating the time shifting of spots of each primary color at the beginning of scan pass s3 for the pattern of spots shown in FIG. 44.

FIGs. 46A through 46F are time sequence diagrams for Example 11, illustrating the time shifting of spots of each primary color at the end of scan pass s3 for the pattern of spots shown in FIG. 44.

FIG. 47 is a diagram of a 4 row by 3 emitting ends per row array oriented in a step configuration, for use in the system of FIG. 1 according to Example 12.

FIG. 47S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 47.

FIGs. 48A through 48E are time sequence diagrams for Example 12 illustrating the time shifting of spots of each primary color at the beginning of scan pass s1 for a pattern of spots shown in FIG. 47S.

FIGs. 49A through 49E are time sequence diagrams for Example 12 illustrating the time shifting of spots of each primary color at the end of scan pass s1 for a pattern of spots shown in FIG. 47S.

FIG. 50 is a diagram of a 12 emitting end linear array for use in the system of FIG. 1 according to Example 13.

FIG. 50S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 50.

FIG. 51 is a diagram of a portion of the pattern of spots shown in FIG. 50S, showing spots where the relative sizes of the spots are not the same for each color and the resulting overlapping of the lines of each color in each line.

FIG. 52 is a diagram of a 12 emitting end linear array for use in the system of FIG. 1 according to Example 14, with the fibers within each RGB Group modified to space the emitting ends closer together.

FIG. 52S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 52.

FIG. 53 is a diagram of a portion of the pattern of spots, and of the resulting overlapping of the lines of each color in each line, projected on a screen by linear spot pattern shown in 52S.

FIG. 54 is a diagram of a 12 emitting end linear array for use in the system of FIG. 1 according to Example 15 angled more from the horizontal aspect than the array of FIG. 50.

FIG. 54S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 54.

FIGs. 55A through 55H are time sequence diagrams for Example 15, illustrating line reordering for a linear spot pattern similar to that of FIG. 54S having an effective row spacing of 1 line and a vertical adjustment between scan passes of 4 lines.

FIGs. 56A through 56C are time sequence diagrams for Example 15 illustrating the time shifting of spots of each primary color at the start of scan pass s3 for a pattern of spots shown in FIG. 54S.

FIGs. 57A through 57C are time sequence diagrams for Example 14 illustrating the time shifting of spots of each primary color at the end of scan pass s3 for a pattern of spots shown in FIG. 54S.

FIG. 58 is a diagram of a 12 emitting end linear array for use in the system of FIG. 1 according to Example 16 similar to that of FIG. 54 of Example 15, with a different assignment of colors to the fibers of the array.

FIG. 58S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 58.

FIGs. 59A through 59H are time sequence diagrams for Example 16, illustrating line reordering for a linear spot pattern similar to that of FIG. 58S having an effective row spacing of 1 line and a vertical adjustment between scan passes of 4 lines.

FIGs. 60A through 60C are time sequence diagrams for Example 16 illustrating the time shifting of spots of each primary color at the start of scan pass s3 for a pattern of spots shown in FIG. 58S.

FIGs. 61A through 61C are time sequence diagrams for Example 16 illustrating the time shifting of spots of each primary color at the end of scan pass s3 for a pattern of spots shown in FIG. 58S.

FIG. 62 is a diagram of an array of fiber emitting ends in an output head whose pattern includes both a single spot per scan line and multiple spots per row, a "totem pole" configuration.

FIG. 62S is a diagram of the pattern of spots projected on a screen using the array shown in FIG. 62.

FIGs. 63A through 63H are time sequence diagrams for Example 17, illustrating line reordering during Subframe A using interlaced scanning for a linear spot pattern similar to that of FIG. 54S, having an effective row spacing of 2 lines and a vertical adjustment between scan passes of 8 frame lines.

FIGs. 64A through 64H are time sequence diagrams for Example 17, illustrating line reordering during Subframe B using interlaced scanning for the linear spot pattern similar to that

of FIG. 54S, having an effective row spacing of 2 lines and a vertical adjustment between scan passes of 8 lines.

FIGs. 65A through 65H are time sequence diagrams for Example 18, illustrating line reordering during Subframe A using interlaced scanning for a spot pattern similar to that of FIG. 27S, having an effective row spacing of 9 lines and a vertical adjustment between scan passes of 8 lines.

FIGs. 66A through 66H are time sequence diagrams for Example 18, illustrating line reordering during Subframe B using interlaced scanning for the linear spot pattern similar to that of FIG. 27S, having an effective row spacing of 9 lines and a vertical adjustment between scan passes of 8 lines.

FIGs. 67A through 67H are time sequence diagrams for Example 19, illustrating line reordering during Subframe A using interlaced scanning for a spot pattern similar to that of FIG. 27S, having an effective row spacing of 5 lines and a vertical adjustment between passes of 10 lines.

FIGs. 68A through 68H are time sequence diagrams for Example 19, illustrating line reordering during Subframe B using interlaced scanning for a spot pattern similar to that of FIG. 27S, having an effective row spacing of 5 lines and a vertical adjustment between passes of 10 lines.

FIG. 69 is a diagram of a 36 emitting end linear array for use in the system of FIG. 1 according to Example 20 employing three rows of the array of Example 16 shown in FIG. 58.

FIGs. 70A through 70H are time sequence diagrams for Example 20, illustrating line reordering for a linear spot pattern similar to that illuminated by the emitting array of FIG. 69 having an effective row spacing of 1 line and a vertical adjustment between scan passes of 12 lines.

FIG. 71 is a diagram of a four row by one emitting end per row "log" array further described in connection with Example 21.

FIG. 71S is a diagram of the spots projected on the screen using the array shown in FIG. 71.

FIGs. 72A through 72D are time sequence diagrams for Example 21, illustrating line sequencing with a 4 x 1 ramp array shown

in FIG. 7 and the pattern of spots in FIG. 7S, with combined colors per emitting end, and an effective one line spacing.

FIGs. 73A through 73H are the horizontal time sequence diagrams for Example 21 using the array shown in FIG. 7 illustrating the timing of the combined spots at the beginning and end of scan pass s1.

FIGs. 74A through 74D are the horizontal time sequence diagrams for Example 21, illustrating the timing of the combined spots at the beginning and end of scan pass s1, using an alternate emitting end array shown in FIG. 71 and the spot pattern of FIG 71S.

DETAILED DESCRIPTION

Because the detailed description of the preferred and alternate embodiments is rather extensive, for ease of reference, we have included herein subheadings descriptive of the content appearing thereafter. These subheadings should not be considered as limiting the scope of the material identified thereby, but are provided merely for convenient reference to the subject matter of the detailed description.

Description of Preferred System

Referring to FIG. 1, a laser projection system 10 according to our invention may be seen to include: laser section 20 supplying light beams in three primary colors red, green and blue that will be directed toward a screen 12; modulation section 30 controlling the intensity of each light beam according to the pixel information; spot projection section 40 for forming the spots of light on the screen 12; scanning section 70 to distribute the spots of light projected by a horizontal scanning subsystem 72 in lines across the width of the screen 12, each traverse referred to herein as a "scan pass", and a vertical scanning subsystem 82 that vertically repositions the scanned beams after each scan pass to different specific vertical locations on the screen, traversing the height of the screen 12; and system controller section 100 which converts the pixel data representing the image into signals that are used by the modulation and scanning sections 30 and 70, respectively, to

illuminate the image indicated in the image data. The controller section 100 also reformats the image into buffers suitable for our display, controls the timing of the horizontal and vertical scanning subsystems 72 and 82, respectively, stabilizes the image, reworks the incoming color values to suit the laser sources, selects and stages the video presentation, and performs diagnostics and keeps usage and diagnostic records.

Advantages of Using Optical Fibers

The flexible optical fibers 42 permit an arrangement of the lasers of the laser section 20 that is convenient for the particular packaging of the preferred laser projection system 10 as a whole. The flexibility afforded by the transmission of the modulated laser beams to the scanning section 70 permits the placement of the laser and modulation sections 20 and 30, respectively, at locations remote from the scanning component. For example, as shown in FIG. 2 showing a schematic perspective view of a commercial theater 11, having the large screen 12, floor 13, seats 14 and ceiling 15. In the theater shown in FIG. 2, the laser, modulation and controller sections 20, 30 and 100, respectively, are located in closet 16 or other convenient location, and fibers 42 extend from the closet 16 to scanning module 18 containing the scanning section 70 positioned on the ceiling 15 or other desirable location at the desired throw distance from the screen 12. In particular, another desirable location may be an existing projector booth, which would allow the laser, modulation and controller sections, respectively 20, 30 and 100, to be co-located with the spot projection section 40 and scanning section 70. Further, as shown in FIG. 4, rear projection may be advantageously employed with only minor modifications to our preferred embodiment.

The laser and modulation sections 20 and 30, respectively, preferred for anticipated initial commercial embodiments of our invention will be more particularly described herein. However, as we noted previously in the Summary of the Invention section hereof, significant advantages are separately and synergistically realized by our use of a spot projection system 40 using multiple

optical fibers, for convenience referred to herein as fiber 42 to conduct multiple separately modulated laser beams to be emitted to the scanning section 70 in a closely spaced array of substantially parallel beams to form a desired spot pattern on the screen 12. While considering the various embodiments of the spot projection, scanning and controller sections 40, 70 and 100, respectively, of our invention described later herein, it should be remembered that a significant advantage of a laser projection system according to our invention is that the use of the fibers 42 enables the use of practically any appropriate laser and modulator components in the laser and modulation sections 20 and 30, respectively. Our invention permits modifications and upgrades of initial lasers and modulation components, and even wholesale changes to substantially different laser and modulator components, without substantial changes to the spot projection, scanning and controller sections 40, 70 and 100, respectively. Improvements in laser and modulator technology may reduce the size and cost of these components.

The use of the fibers 42 to transmit the laser beams to the scanning module 18 thus enhances the utility of the system according to our invention, in that the laser sources, modulators, scanning components, and controller electronics may be separately replaced, upgraded or modified without the need to alter the remaining components. Further, the use of fiber allows great flexibility in using smaller lasers and modulators, by facilitating one laser per color per line, several emitting ends and lasers per color per line, and the use of fiber coupling-based beam coupling.

Spot Projection Section

Referring again to FIG. 1, in the spot projection section 40 of the system 10 according to our invention the modulated beams are inserted into optical fibers, referred to herein as fibers 42, and emitted in a pattern that is projected through the scanning section 70 and thence to the screen 12. In general, each of the fibers 42 has an insertion end 44 and an emitting end 56, although when fiber-based beam couplers 29 are optionally

employed there may in aggregate be fewer emitting ends 56 than insertion ends 44. While not required within our invention, fiber may also be used to transmit the unmodulated beams from the lasers 22, 24, or 26 to the modulators 32. Such fibers 43 may also have fiber-based beam couplers 29, and have launchers at the lasers to launch the beam into the fibers 43.

Referring to FIG. 3, associated with each insertion end 44 of the spot projection section 40 is a fiber input head 46 that positions that insertion end 44 with respect to input optics or lens 48. The technology for inserting laser beams into optical fiber is well known. FIG. 9 shows the fiber emitting ends 56 of all of the fibers 42 mounted in a desired array in output head 58, preferably in the form of an epoxy block fixed to a chassis in a desired position with respect to an output lens 60. It should be understood that FIG. 1 shows only three modulators, fibers 42, fiber input heads 46 and input lenses 48 to avoid unnecessarily cluttering the drawing, and that in our preferred system, twelve separate modulators, fibers 42, input heads 46 and input lenses 48 would be employed.

FIG. 5 shows an exemplary arrangement of the fiber emitting ends 56 in an array or configuration of four rows of emitting ends having three emitting ends per row such that four rows of spots, with each row having each of the three primary colors, are projected to the screen 12 by laser beams emitted from the emitting ends 56 of the fibers 42. It is not possible with conventional reflective and refractive optics to make a large diffuse spot of light or an array of spots into an infinitely small spot. An image of the source must be formed. By using each of the fiber emitting ends 56 as the image forming or relay or spot projection device for transmission of a single spot, we form an image of the array of emitting ends 56 as a pattern of spots on the screen 12. Each individual spot can be diffraction limited in size, as discussed herein.

Since the spots of each row are traveling along the same desired path across the screen 12, and striking the same apparent dot location at different times but within the time limit for

integration by the eye, we can make the desired composite color at a particular dot location by timing the modulation of each separate color beam at the necessary intensity to occur when each color beam arrives at the desired dot location.

Referring again to FIG. 5, the pattern of spots thus formed by the array of fiber emitting ends 56 is preferably (but not required by our invention) comprised of more than one emitted beam or more than one row of horizontally aligned beams. In our preferred embodiment, four rows of beams emitted from four rows of emitting ends 56 are preferably vertically spaced apart to scan four distinct lines of spots onto the screen 12. In the embodiment shown in FIG. 1 and further described herein one modulated beam is used for each color in each row of fibers 42. Four rows of three beams are scanned in a pattern of spots together to form four spaced apart lines with each horizontal scan pass. For this configuration, this requires three colors times four lines, or twelve separate fibers 42. Thus, the modulated spot projection section 40 of the theater laser projection system 10 preferably includes twelve fibers 42, emitting twelve separately modulated laser beams from twelve emitting ends 56 as shown in FIG. 5 to produce twelve spots on the screen in a pattern of 4 rows of 3 spots per row, as shown in FIG. 5S. For consistency, in the remaining figures describing the preferred array of emitting ends and alternate arrays, we will sometimes describe instead the pattern of spots produced by the laser beams emitted from, and conforming to, the array of emitting ends 56, sometimes consisting of 56R red emitting ends, 56G green emitting ends, and 56B blue emitting ends. In this and subsequent drawings, all emitting ends may not be labeled, so as to avoid cluttering the drawing. It should be understood that because of the lens used in our preferred system, the actual position of the spots is reversed on the screen 12 from the position of their corresponding emitting ends in the array, albeit in the same relative pattern. As described in more detail later herein, we refer to the rows of emitting ends from bottom to top as RowA, RowB, RowC and RowD. Using this convention, it

may be seen that the lens inverts the image about the axis of the lens, such that the beam emitted from the left-most emitting end of the bottom RowA of the emitting end array will be projected as the right-most spot in the top RowA of the corresponding spot pattern projected on the screen.

Any focusing optic may be used in place of the preferred single achromat output lens 60 illustrated herein, such as a focusing mirror, other suitable lens or lens combination, or holographic element. Such focusing optic should preferably result in the light beams emitted from the emitting ends being substantially parallel when leaving the focusing optic, such as illustrated in FIG. 16, to produce a pattern of spots corresponding to the configuration of the emitting ends.

<u>Optical Fibers of Spot Projection Section</u>

Our preferred fiber is a larger-than-single-mode fiber 42, such as the SMF-28 step-index 8.5 micron fiber from Corning Glass Works, or equivalent. This fiber is only slightly larger than the 4 to 5 micron diameter required for preserving a single mode beam with visible light. With this fiber, the beam image is more than adequate at high resolution, despite not being the ideal theoretically possible. Our invention may also use to advantage almost any other "light pipes" other than the single mode or nearly single mode step-index optical fibers described previously herein. These alternates may, especially with further advances in optical fiber transmission, include fibers such as gradient index (GRIN) fibers where the change in index between the core and cladding is not practically instantaneous as with the step-index fibers, but rather increases or decreases gradually from center to external surface of the cladding. We may also include hollow glass tubes, light pipes, optical waveguides, liquid filled glass tubes, or hollow tubes made of other materials.

In our preferred fiber output head 58 assembly shown in FIG. 5, with the fibers adjacent to one another, the spacing between the centers of the fiber emitting ends 56 is between 70 and 125 microns. The output lens 60 is preferably a 1/4 inch or larger diameter simple two-element achromat of 12.5 to 25 mm focal

length. For our preferred system 10 shown in FIGs. 1 and 9, the lens 60 is positioned at a distance from the emitting ends 56 that is appropriate, in consideration of the throw distance from the emitting ends 56 to the screen 12, to focus the beams to produce a pattern of spots, such as shown in FIG. 5S, having the desired resolution on the screen 12 without an intermediate focal point.

The emitting ends 56 are secured within the output head 58, and are preferably arranged in the output head 58 in the configuration shown in FIG. 5 in a rectangular array or pattern four fibers high and three fibers wide, with one laser a beam in each of the three primary colors issuing from one of the emitting ends in each row. At the emitting ends 56, the light emits from the fibers 42 and all of the individual beams travel through a single output lens 60. However, it should be understood that our invention should not be limited to this particular pattern, as a multitude of patterns could be employed, as described herein. Further, arrays having two, three or more than four vertically spaced rows of fibers 42 and more or less than three fibers 42 per row could be employed. We have selected the four row by three fibers per row array for the sake of economy and performance, based on the criteria discussed previously herein, and described in more detail herein.

Spot Projection Section Configurations

It will be understood that alternate patterns, arrangements and numbers of emitting ends for producing spots of different colors or multiples of colors could be employed and be within the scope of our invention. Although it is not feasible in this context to provide a comprehensive catalog of the possible patterns and arrangements of fibers, modulators and lasers, the following examples, and additional examples described in connection with alternative spot patterns, illustrate the wonderful flexibility and power of our use of fibers and multiple line scanning. For example, in order to achieve our most preferred resolution of 3000x2000p, it may be necessary, for example, to add two additional rows of emitting ends for a

configuration of 6x3 fiber emitting ends to project a spot pattern of 6 rows of 3 spots per row or 18 fibers or spots in total. The additional rows permit scanning of more lines and spots, while continuing to realize the benefits of our invention with respect to modulation rate for each modulator of the system, and to keep the scanning system components within acceptable economy and resolution capabilities. It should be understood that such a fiber emitting end pattern could be employed with our preferred system in place of the 4 row by 3 emitting ends per row array shown in FIG. 5, although this configuration requires additional modulators and other components.

Different emitting end arrays producing various spot patterns may also be employed to take advantage of availability of different laser sources. For example, as shown in FIG. 8, it may be possible to use two or more less powerful blue lasers for each row (rather than one per row as in FIGs. 1 and 5) to produce the desired intensity of blue spots on the screen without using combining optics by using a 4x4, 4x5 or 4x6 (FIG. 8) emitting end configuration, as illustrated by the 4x6 spot patterns shown in FIG.8, such that in each row of emitting ends, one emitting end emits a red laser beam, one emits a green laser beam, and the other two or more emitting ends 56 emit blue laser beams, each having a portion of the total power desired for blue.

A 4x4 emitting end configuration producing a 4x4 spot pattern could also be used for a different reason, namely the use of four different wavelengths to form the composite color at each dot location. Examples of the wavelengths that might be suitably employed are a red in the 605 nm range, a green in a 530 nm range, a blue in the 470 range, and another red in the 660 nm range. As described in more detail later herein, the color values for each pixel of video data could be suitably converted to the four color scheme by an appropriate color lookup table in the controller section 100 in a manner familiar to anyone skilled in the art. For example, the red in the 660 nm wavelength might be activated when a deep red is needed, while the photoptically more

efficient red at the 605 nm wavelength is utilized to form most composite colors and the less deep red colors.

It would also be possible to employ our invention by combining two laser beams of different wavelengths, such as a red beam in the 605 nm wavelength and a red beam in the 660 nm wavelength, after their separate modulation, into a single fiber, thereby emitting a beam of both separately modulated wavelengths from a single emitting end of the fiber. Similarly, it would be possible employing our invention to combine the separately modulated beams of two or more different primary colors for transmission through a single fiber, using fiber-based beam couplers or other techniques. In this way, a 4x3 or 4x4 emitting end output head configuration could accommodate a combination of laser beams of 4, 5, 6 or more separate wavelengths needed to form a composite spot at dot locations on the screen to produce a particular combined color.

As described later herein in more detail in Example 9 employing a 4x6 output head configuration, for a 4 row by 6 spots per row spot pattern shown in FIG. 8, six beams are reordered or time shifted so that the blue beams strike those dot locations in each line that require a blue component. Thus, our invention permits the simple addition of the number of necessary fibers and emitting ends to produce the desired color intensity with the lasers available or desired.

It should further be understood that fibers may be used to transmit the modulated laser beams to the scanning components without employing multiple line scanning especially in monochrome applications, either with one color or with black and white, where a single emitting end directs the beam to the scanning components. Further, a single row of emitting ends may be employed to advantage without multiple line scanning, especially with scanning components having a greater scanning capability than the economical and simple scanning components employed with our preferred system shown in FIGs. 1 and 9 or where resolution requirements are lower.

It should be noted at this point that the HDTV resolution of which the preferred embodiments described herein are capable is not the upper limit, but is an intermediate implementation constructed because of the availability of HDTV signals in the near future. However, as the available resolution of video sources increases, our invention will facilitate the use of such enhanced sources for laser projection.

Spot Projection Section Optical Components

As schematically shown in FIGs. 1 and 9, the spot projection section 40 of this embodiment further preferably includes a single output lens 60 to focus all of the beams emitted from each of the emitting ends 56 onto the screen 12 through the scanning section 70. Given that the fiber emitting ends 56 are placed close to the optical axis of the single output lens, preferably as shown in FIG. 5, the spots at the distant target on the theater screen 12 as shown in FIG. 5S will be an enlarged image of the pattern of the twelve (actual count depends on number of fibers 42 in the output head 58) fiber emitting ends 56, each at or near the diffraction limit for its wavelength and the diameter of the beam on the output lens 60. This assumes that the fibers 42 are of the single mode or near single mode type. A complete discussion of the theory of diffraction limits, that is, of how spot size at the final focusing optic and wavelength affects the spot size at a distant target is given in any modern text on Gaussian beam optics, such as "Useful Optics", Walter T. Welford, University of Chicago Press, 1991, Ch. 7, pp. 44-57.

The emitting ends 56 are close enough together that the beams from each travel, nearly enough for our purposes, but not exactly, on the axis of the output lens 60. This also means that the output lens 60 can be, for example, a simple best form laser spherical or an aspheric singlet (both with a single element), or a simple achromat doublet or triplet. The use of a single output lens 60 also avoids complex optics and alignment problems inherent in using a separate output lens for each fiber emitting end 56, for each row as a whole or for all ends of each color. For convenience, we refer herein to the beams representing the

pattern of spots projected by the array emitting ends onto the facet of the polygon mirror and thereafter the screen, as the "aggregate beam".

We note that while we have mentioned lenses as optics for beam shaping and manipulation, we do not exclude, within the realm of our invention, the use of curved mirrors, holographic optical elements and other elements adapted to deflect or refract the laser beams in a desired manner.

Laser Beam Insertion and Emission with Optical Fibers

There is a difference between the insertion and emitting ends 56 of the fibers 42. As described above, for the insertion end 44 of each fiber 42 there will usually be one beam and one lens 48 for each fiber 42. Where the beams are combined within the fiber using fiber-based beam combiners 29 there will be more insertion ends 44 than emitting ends 56. The individual fibers are then grouped into a single assembly with the fibers ends arranged so that the emitting ends form a desired array. All(for example, twelve) of the beams will each travel through one of the twelve fibers, be emitted from an emitting end 56 of each fiber 42 and thence travel as an aggregate beam through the single output lens 60. If the beams are different colors and the emitting ends 56 are equidistant from the output lens 60 as shown in FIG. 4, then with a simple lens as the output lens 60 the focal length of the output lens 60 may be different for each color. Only one color would then be in exact focus on the screen 12, and the other two will be out of focus to an unacceptable extent. Our use of an achromat lens as the output lens 60 in the preferred embodiment satisfactorily resolves this problem.

Scanning Section Components

The function of the preferred scanner or scanning section 70 according to our invention is to sweep the laser spots across the screen 12 in a vertical succession of horizontal lines. Thus, the scanner is positioned to deflect the light beams emitted from the emitting end of each of said fibers to simultaneously illuminate separate locations on the viewing surface. In the scanning section 70 of the projection system 10 shown in FIGs.

1 and 9, two scanning components are employed. One is called the "line scanner", or horizontal "line" scanning subsystem 72, since it scans the spots produced by the beams in horizontal lines in a sweeping, scanning or line direction along dot locations across the screen 12. We prefer a type of mechanical line scanner such as rotating polygon mirror 74 shown in FIGs. 1 and 10, having between 24 and 60 mirrored facets 76, but most preferably 28 facets. It is possible to replace the mirrored facets 76 by small lenses or by holographic material, but these solutions tend to increase the cost of the line scanning components and introduce other issues. The polygon mirror 74 is rotated by polygon mirror motor 78, typically in a range of 25,000 to 50,000 rpm. The speed of the polygon mirror motor 78 is preferably controlled by polygon mirror controller 80. Our invention facilitates the use of a lower cost off-the-shelf line scanner in the form of the polygon mirror 74, such as in our preferred motor/polygon mirror and driver assembly similar to Model No. 1-2-2693-601-34 manufactured by Lincoln Laser Company of Phoenix, Arizona.

Referring to FIG. 9, the other scanning component of the scanning section 70 is called the "frame scanner", or vertical frame scanning subsystem 82, since it vertically displaces the projected lines, causing successive scans to move down the screen 12. The frame scanner cycles 50 to 120 times a second in keeping with the desired refresh rate. A preferred form of frame scanner is the galvanometer driven mirror 84 shown in FIG. 9. The mirror 84 is mounted with a galvanometer motor 86 that pivots the mirror 84 to reflect the projected lines from the top to the bottom of the screen 12 during one frame. This form of frame scanner is relatively inexpensive, and our invention facilitates its use in a video laser projection system. We prefer to use a galvanometric frame scanner manufactured by Cambridge Technology, Model No. 6860M.

This preferred continuous adjustment mirror moves the spots forming the lines down the screen to accomplish continuous raster scanning as previously described and tends to produce slightly

slanted lines. Given the large number of lines being written at the desired resolutions, this slight slant is not noticeable to the viewer, being approximately 0.8 inch from one side of a typical movie theater screen to the other, and avoids the complicated and more expensive stepped adjusting, non-continuous raster scanning, necessary to adjust each scan pass or line discretely. Further, if the discrete adjustments of a stepped adjusting mirror are not consistent or quick enough, i.e., aren't completed between the end of one line and the beginning of the next, undesirable image artifacts may be introduced.

The preferred galvanometer mirror 84 has a recovery rate from the bottom of the frame to the top of the next frame of approximately one millisecond which is adequate for the purposes of this system. Other frame scanning apparatus, such as large rotating polygon mirrors, acousto-optic techniques, and resonant mirrors may be used within the contemplated scope of the present invention. Further, although not required, we prefer for convenience to employ a relay mirror 81 to reflect the aggregate beam from the galvanometer mirror 84 in the appropriate path to the screen 12.

FIG. 16 illustrates the paths of beams from their emission from three of the emitting ends through the output lens 60 to their substantially coincident position on the mirror facet 76 of the polygon 74. The preferred single achromat output lens 60 enables the location of the emitting ends and lens 60 in a position to focus the collective beams to form the minimum size of "aggregate spot" on the facet 76 for reasons described below. In our preferred system, the size of the mirrors in each of the galvanometer mirror 84 and polygon mirror facets 76 must be larger than the aggregate spot image reflected from the facet 76 by the pattern of beams directed from the output lens to the polygon mirror facet 76 and thence to the galvanometer mirror 84. The size of the galvanometer mirror 84 must be large enough to contain the pattern of beams or aggregate spot when its incidence is at an angle in one axis, and to contain the beam on the other

axis as it is swept from side to side by the polygon mirror facet 76.

As an alternative to the simple output lens 60 described above, we may narrow the aggregate spot on a facet 376 of a polygon mirror 374 similar to the polygon mirror 74 by changing the focus of an output lens 360 as shown in FIG. 10, causing the beam from the polygon mirror facet 376 to expand, and then focusing the consequently wider pattern of aggregate beams reflected from the polygon facet 376 again with a complex lens 366, such as an F-Theta lens, onto the screen 12. This approach allows for smaller facets 376 because the pattern is focussed to a smaller area of the polygon mirror facets, but requires the complicated lens array 360 and 366. Conversely, in the preferred system shown in FIG. 16, we allow the aggregate beam emitted from the output head 58 to be reflected onto the polygon mirror facet 76 so that the aggregate spot is almost exactly the same size on the polygon mirror 74 as the aggregate spot is as it emerges from the output lens 60, and no further focusing lens, especially no complicated lens arrangement as in the system of FIG. 10, is required. From the foregoing alternatives, it may be understood that our simple output lens 60 and avoidance of focusing lens 366 after the horizontal and vertical scanning subsystems 72 and 82, are major factors in avoiding image artifacts and in attaining high resolution and high optical efficiency in our preferred system. Thus, our system uses a greater proportion of the power generated by the laser sources, because less laser beam power is sapped by complex optics. This optical efficiency allows our system to employ lower aggregate laser power than would be required with prior art laser projection systems for large screen projection.

Our preferred implementation shown in FIGs. 1 and 9 calls for the image beam to strike the polygon mirror facet 76 first and then the galvanometer mirror 84. Alternatively, as shown in FIG. 11, with a taller facet 476 of polygon mirror 474, the opposite order of horizontal and vertical mirror reflection may be implemented allowing for a smaller galvanometer mirror 484 and

galvanometer transducer 486. Either vertical or horizontal scanning component order, or any other scanning technique that moves a beam for that matter, falls within the purview of the present invention.

As previously noted, referring again to FIGs. 1 and 9, the rotating polygon mirror 74 we prefer to use is relatively inexpensive. However, while it is possible with diamond turning to create mirror facets 76 in such a polygon mirror that are optically indistinguishable, it is not possible to fabricate those facets 76 so that their vertical and horizontal pointing accuracy is sufficiently accurate for this application. Some consideration in the system design must be made to compensate for the inaccuracies, at least at the resolutions desired. Those skilled in the art will recognize that there are many well known techniques for correcting for vertical facet pointing errors. Referring again to FIG. 9, the horizontal errors are preferably corrected with another component of the facet error detection assembly 90, which optically detects on a continuous basis when each facet 76, referred to hereinafter as the "active facet", is in fact in the correct position to initiate scanning of the line at the appropriate dot locations on the screen. This detection is accomplished by sensing a low power laser beam from facet detection laser 92 with photo detector 98 positioned such that the active facet 76 is in the exact position for initiation of a line. Thus, the horizontal error is corrected by shifting the timing of release of data to initiate the projection of spots by the modulated laser beams incident on the facet 76 so that the beam writes spots from appropriate data pixels at the appropriate position on the facet and consequently on the screen, thereby automatically correcting the horizontal facet error.

Scanning Section Optical Configurations

There are two basic configurations of optics for image scanning systems, pre-scan optics and post-scan optics. Almost all prior art laser projectors that use polygon mirrors use pre-scan optics similar to that shown in FIG. 10, where the lens comes after the scanning optics (so named because the SCANNING

occurs BEFORE the lens) because of some of the following advantages: the output field can be made flat, the final focusing optic that determines the resolution is closer to screen, and barrel or pincushion distortions may be introduced or eliminated to compensate for non-ideal screen surface profiles. However, pre-scan optics have the following disadvantages: color separation, uneven focus center-to-corner, uneven brightness center-to-corner, and require larger complex lenses, especially for color images and high resolution.

Referring to FIG. 2, the throw distance, that is the distance between the scanning section 70, or in FIG. 2 the scanning module 18, and the screen 12, is fixed and is determined by the angle between facets 76 on the polygon mirror 74 and the desired image size. Our preferred system for the motion picture theater application does not require changes in throw distance or a variable throw distance. However, an alternative embodiment would include one or more Barlow lenses 62, as shown in FIG. 12. Our preferred lens is a small, simple two element negative achromat. This negative lens expands the scanned image 38 on the screen 12 primarily in the horizontal direction to a new, wider image 36, thus allowing the projector to be closer to the screen, as may be required in modern theaters. Utilizing a different such lens may also allow for simple changes in screen image aspect ratio. For instances where the throw distance must be lengthened, the use of a weak positive achromat would narrow the scan angle without loss of scan time and thus without loss of light energy. In a system capable of two (or more) throw distances or aspect ratios, a simple mechanism would be required to insert or change the Barlow lens, change the focal distance vis-a-vis the lens 60 and preserve the desired effective row spacing, preferably, in an embodiment such as described in Example 15, by slightly rotating the output head.

The advantage of this optical configuration, particularly within our preferred post-scanning embodiment, is that there still is no intermediate virtual image formed before the screen,

in contrast with typical "pre-scanning" optical configurations, thus preserving resolution and orthogonality.

While pre-scan optics may be used with embodiments of our invention, we prefer to use a post-scan optical configuration (again so named because the SCANNING occurs AFTER the lens), such as shown in FIGs. 1 and 9, because post-scan optics give better resolution and brightness, and avoid the image degradation and power losses typically resulting from complex optics. The use of the simple optics of our preferred post-scan system, in conjunction with a fiber head according to our invention, make small spots and high resolution feasible.

Reordering of Video Data for Multiple Spot Projection

The scanning components in our preferred embodiment determine the manner in which the four spaced apart rows of three spaced apart color spots are reordered in accordance with our invention. The closest feasible physical spacing of the emitting ends 56 in the output head 58 of our preferred embodiment shown in FIGs. 1 and 5, assuming a desired resolution of 1920x1080p, produces an effective vertical row spacing of approximately ten or more lines, and a horizontal spacing between red, blue and green color spots of approximately 10 or more dot locations. Although we later provide examples of such spacing, the following illustrations of this data reordering assume a vertical spacing of five lines (4 lines of dot locations between rows of spots of the spot pattern on the screen) and a horizontal spacing of five dot locations within a row (four dot locations between each spot of a row of the pattern of spots on the screen).

This requires a re-ordering of the video data. FIGs. 13A through 13J and 14A through 14E illustrate the effect of reordering the writing of lines and dot locations within lines for the first embodiment of our invention, as briefly described in the Summary of the Invention section hereof, assuming a frame scan top to bottom, line scan left to right, and an effective row spacing of five lines and a horizontal spacing of five dot locations within a row. In FIGs. 13A through 13J, the composite color for each pixel is written at the appropriate dot location

by scanning the image formed by the emitting ends 56 of the fibers 42 in one horizontal row of the output head 58. In the exemplary order, the dot location is first written by a red spot represented by "×", then by a green spot represented by "+", and by a blue spot represented by "O". A green spot overwriting a dot location already written with a red spot is shown by "*" and a blue spot overwriting a dot location already written by red and green spots is shown by "⊛". In FIGs. 13A-13J the dot location currently written by a spot at a particular time "t" during a particular scan pass is indicated by boldfacing, and a spot that is blanked because it will not at that time write a location within the frame on the screen is indicated by outlining.

For convenience in describing the time reordering of the color values of the pixel data for a particular dot location, also referred to as time combination or time combining, we refer to the time at which each adjacent dot is illuminated by the spot of the laser beam emitted by the appropriate emitting end, starting with the dot location at the beginning of the frame line, as time t1, t2, t3,....For example, at time t1, the first dot location of a line is written, at time t2 the second dot location of a line is written. For the preferred 1920x1080p resolution, the time will range at least from time t1 to time t1920, and possibly to time t1921 and further, depending upon the amount of overscan necessitated by the dot spacing between spots in a row of the array.

Time Combining of Multiple Spots During Line Scanning

As shown in FIGs. 14A through 14E, to be discussed in more detail later herein, the 4 row by 3 spot per row array projected by the preferred embodiment preferably writes the fourth line of the frame on the first scan pass s1. Consistent with FIG. 13A, in the scanning of this line with the bottom row of spots, at time t1 of the first scan pass the first pixel in the fourth line is written by the red × beam modulated for the value of the red color assigned to that pixel in the video data, while the green and blue beams, which if activated would write pixels to the left of the frame (shown with outlined, lighter figures) are not yet

activated (also referred to herein as "blanked" and sometimes identified by "b" in the Tables below) by their respective modulators. Continued rotation of the polygon mirror 74 successively positions the spot produced by the red beam at the locations of the second, third, fourth and fifth dots, which are respectively written at times t2, t3 (shown in FIG. 13B), t4, and t5 with the values of red assigned thereto in the pixel data, and the green and blue beams are still blanked. As shown in FIG. 13C, further rotation of the polygon mirror 74 positions the red × spot at the sixth dot location, and the first and sixth dots are respectively written at time t6 by red × and green + spots having the values of red and green respectively assigned thereto, with the blue spot still blanked. Continued rotation of the polygon mirror 74 successively positions the red × and green + beams at the locations of the seventh, eighth, ninth (shown in FIG. 13D) and tenth dots, and at the second, third, fourth (FIG. 13D) and fifth dots, respectively, which are respectively written at times t7, t8, t9 (FIG. 13D) and t10 with red × and green + spots having the values of red and green respectively assigned thereto, and the blue beam remains blanked because it is not yet in position to be written within the frame. As shown in FIG. 13E, still further rotation of the polygon mirror 74 positions the red × beam at the location of the eleventh dot, and the first, sixth and eleventh dots are written at time t11 by the red ×, green + and blue ○ beams with the values of red, green and blue respectively assigned thereto. Continued rotation of the polygon mirror 74 successively positions the red ×, green + and blue ○ beams at the locations of the remaining dots in the fourth row of the frame with the values of red, green and blue respectively assigned thereto. It is apparent from the illustration of FIGs. 13A-13E that with this method according to our invention, a spot of each color modulated for the value of that pixel in the image data is projected for every dot in that line.

Referring now to FIG. 13F, at the end of the first scan pass s1, the last dot 1920 in the line will be written at time t1920 with the appropriate red × value, and the dots 1915 and 1910 with

green and blue spots, respectively. Referring to FIG. 13G, continued rotation of the polygon mirror 74 will at time 1921 write dots 1916 and 1911 for green and blue, respectively, with the red beam blanked. The process repeats until, as shown in FIG. 13H, at time t1925 the green × spot writes the last dot location in the line. As shown in FIG. 13I, continued rotation at time t1926 will write dot location 1916 with the blue O spot, and the green and red spots are blanked. Finally, at time t1930 as shown in FIG. 13J, the blue O spot writes dot location 1915, which has already been written at times t1920 and t1925 by the red and green beams, respectively, and at such time t1930 the red and green beams remain blanked, whereupon the fourth line of the frame has been completely scanned. After the generation of the fourth line, the galvanometer mirror 84 adjusts, or has adjusted, downward a spacing equivalent to four lines from the beginning of the last set of lines, and the next facet 76 of the polygon mirror 74 is in position to begin writing the next set of four lines at scan pass s2. In our preferred implementation as noted previously the galvanometer mirror 84 may actually move continuously so that all of the lines forming the image slant a minute amount, and consequently the spots arrive four lines down at the start of the next line scan pass as if the galvanometer mirror 84 had moved all at once between lines.

The positioning of separate emitting ends 56 for each row of the output head 58 projecting a pattern of spots such that they are separated on the screen by more than one dot location is preferred for ease of fabrication of the output head 80. However, it is possible, as described for an alternate embodiment herein to combine the different colored beams prior to insertion into the insertion ends of the fibers 42, such that four vertically adjacent single emitting ends emit spots of composite color. These composite color spots would be directed to the scanning components and thence to the screen, thereby obviating the need for the reordering of horizontal pixels of each line.

It should also be understood that the adjustment of the time at which a beam of a desired color and intensity strikes a

particular dot location on the screen within each line, and as shown in later embodiments within different lines, is a factor of data manipulation by the controller section. Hence, the assignment of colors to the emitting ends within each row, and as described later the relative position of emitting ends within rows, may differ from row to row of emitting ends. That is, the time combination used to write the line of spots projected by the beams from one row is not necessarily that same as that required to write the line of spots projected by the beams emitted to any other row of the output head array of emitting ends.

Reordering of Multiple Rows of Spots During Frame Scanning

Referring again to FIGs. 14A-14E, although not restricted to such a scheme, for the first embodiment of our invention described herein, each vertical adjustment of the preferred galvanometer mirror 84 is four scan lines, equal to the number of rows of emitting ends of the output head 58. For purposes of illustration in connection with the first embodiment, the effective row spacing between each row of the emitting ends 56 in the output is five lines. Unlike the reordering required to write a beam for each emitting end 56 of a row on the same spot, for vertical scanning it is generally desired to write each unique line with only one of the rows of the output head 58. Thus, when the frame is complete, each row of the output head 58 will have written a unique set of lines, and all of the lines in the frame will have been written once each.

For convenient reference herein in describing line reordering, we refer to the rows of spots projected from the emitting ends of the output head of the preferred embodiment from top to bottom as rows "RowA", "RowB", "RowC", and "RowD", respectively. Further, for each of the figures involving the 4 row by 3 emitting ends per row output head configuration, for each scan s(x), where x is the sequential number of horizontal scans (e.g., for the preferred 1920x1080p resolution, s1 at the first scan pass at x=1, s2 at the second scan pass at x=2, and s273 at the last scan pass at x=273). Lines written by RowD, RowC, RowB, RowA of spots written by the beams emitted from the

emitting ends are indicated by "DDD", "CCC", "BBB", "AAA", respectively. As with FIGs. 13A-13J, for FIGs. 14A-14E, currently written lines of the frame are indicated by boldfacing ("AAA", "BBB", "CCC" and/or "DDD", and blanked lines are indicated by outlined "AAA", etc.

For the example of the preferred embodiment in FIG. 1, 5 and 5S, the first line written at scan pass s1 is preferably the fourth line from the top of the frame (line L4) with the spots (one of each color) of the bottom row RowD, collectively shown by the boldfaced DDD in FIG. 14A, while RowC, RowB, and RowA of spots are blanked as shown by the outlined CCC, BBB and AAA in FIG. 14A. After the entire line L4 is scanned by rotation of one of the polygon mirror facets 76, the galvanometer mirror 84 will preferably have adjusted downward a distance equivalent to four frame lines, and scan pass s2 will be initiated when the next succeeding facet 76 is in position. Because of the effective five line row spacing (or 4 lines of dot locations between rows of spots) of the rows of spots as noted previously, lines L8 and L3 of the frame are written as shown in FIG. 14B during scan pass s2 by the spots of RowD and RowC (boldfaced DDD and CCC in FIG. 14B), while RowB and RowA of spots remain blanked (outlined BBB and AAA in FIG. 14B). Note that the non-boldfaced DDD in line L4 of the frame at scan s2 shown in FIG. 14B, and in all of the remaining figures relating to similar line reordering, denotes that those frame lines were previously written, in this case during scan pass s1 shown in FIG. 14A.

By the time of scan pass s3 shown in FIG. 14C, the galvanometer mirror 84 will again have adjusted downward by a distance equal to four lines, lines L12, L7 and L2 will be written by the spots of RowD, RowC and RowB (boldfaced DDD, CCC and BBB in FIG. 14C) and the spots of RowA are still blanked (outlined AAA in FIG. 14C). At scan pass s4 shown in FIG. 14D, lines L16, L11, L6 and L1 are written by the spots of RowD, RowC, RowB and RowA. At scan pass s5 shown in FIG. 14E, lines L20, L15, L10 and L5 are written by the spots of RowD, RowC, RowB and RowA. Thus, it can be seen from this illustration that by the end of

scan pass s4, lines L1 - L4 of the frame have all been written, albeit out of order; of the next four lines, only lines L6, L7 and L8 have been written; and of the following four lines, only lines L11 and L12 have been written, and of the fourth set of four lines, only line L16 has been written. The not-yet-written lines will be written on subsequent passes.

As shown in FIGs. 15A, 15B, 15C and 15D, assuming a resolution of 1920x1080p, continued regular downward adjustment of the galvanometer mirror 84 will eventually result in writing lines L1065, L1070, L1075, and L1080 of the frame with spots from all of RowA, RowB, RowC and RowD, respectively, at time s(1080/4), or scan pass s270. At scan pass s271, lines L1069, L1074 and L1079 will be written by spots of RowA, RowB and RowC, and RowD will be blanked. At scan pass s272, lines L1073 and L1078 will be written by spots of RowA and RowB, and RowC and RowD will be blanked. At scan pass s273, line L1077 will be written by spots of RowA, and RowB, RowC and RowD will be blanked. After line L1077 is written as shown in FIG. 15E, the frame is complete, and the galvanometer mirror 84 is adjusted to the top of the frame and the next frame is commenced. Thus, there will be three scan passes at both the top and bottom of the frame where at least one row of spots is blanked. Alternate embodiments having different reordering sequences are disclosed herein.

Based on the foregoing examples, a primary function performed by the controller section 100 may be more generally described as controlling the reordering of the digital input signals required for our invention. In the case of the first embodiment, the controller section 100 must provide the pixel data to the modulator section so that the beams inserted into each fiber are modulated to produce a color of the desired intensity at each dot location on the screen 12 at the time the scanning section 70 is in a position to illuminate that particular dot location. It should be understood that different spacings of the rows of emitting ends is possible, and even desirable. Several examples of such different row spacings, and of alternate head configurations, are described later herein.

Alternative Scanning Components

Continuing with the foregoing discussion of the scanning section, although we prefer to use moving mirrors in the form of a rotating polygon mirror 74 with multiple facets 76 for horizontal scanning and a galvanometer mirror 84 for vertical adjustment, our invention may facilitate the use of alternative scanning methods and components. Some of these include using two pivoting or tilting mirrors moving by galvanometers or resonance scanners, acousto-optic beam steering, digitally controlled chip-mounted mirrors, piezo electrically controlled vertical and horizontal mirrors, or holographic beam steering replacing the polished facets 76 of the polygon mirror 74 of the first embodiment.

Modulation Section

Within our preferred embodiment, and at exemplary resolutions, refresh rate and emitting end configurations, each beam must be continuously modulated to assure as many as 30 million values per second. In the modulation section 30 schematically shown in FIG . 1, we prefer to utilize an acousto-optic crystal for the modulator 32 because of its ability to completely turn off the beam, permitting our desired high contrast ratio, and because its modulation is continuously variable. The modulator 32 is positioned between each primary color laser light source and the spot projection section. Each of the beams is thus directed through modulator 32 toward the spot projection section thence to the scanning beam projection component, where it flows through to a particular point on the screen 12. This action occurs exactly when the pixel information indicates that such spot on the screen 12 is to be illuminated.

As noted previously, additional techniques for modulating laser beams have been used with varying success in other applications, which could take advantage of our invention. With further technological advances, these additional techniques could be used to advantage in further possible embodiments of our laser projection system 10.

When using certain kinds of lasers, the input power to the laser itself can be varied as required for each pixel. If suitable advances in these laser technologies are accomplished, continuously variable laser beams from such lasers could be inserted into the fibers 42 of our system 10 and scanned with the scanning subsystem of our first embodiment. Such a system would have much reduced size, as the larger, more expensive laser and modulation components could be uniquely replaced in a system 10 according to our invention by such newly developed continuously modulatable diode lasers.

Alternate Modulation Section Configurations

In our preferred embodiment, and generally within our invention, the number of modulators 32 is equal to the number of emitting ends of the output head 56, with some exceptions, notably where composite beams are created as in Example 21 or as above where the modulators are in fact one with the lasers. However, it may be advantageous, and is within the scope of our invention, to use more modulators, either for economic reasons, to lower power levels within the individual modulators or to accommodate changes in the laser section 20. Such alternatives are enabled by our use of fiber, multi-line scanning, time combination and fiber-based beam coupling. Some examples of these alternatives are shown in more detail later herein in connection with FIGs. 6, 23, and 24.

Laser Section - Wavelengths of Colored Beams

The laser section 20 shown as a block in the diagram of FIG. 1, and shown in more detail in FIG. 17, supplies the light beams in the three primary colors to be eventually directed toward the screen 12, preferably includes red lasers 22, green lasers 24 and blue lasers 26. These lasers must have appropriate wavelengths so that all, or almost all, visible hues can be made up by combining various intensity of these primary wavelengths. In the anticipated commercial systems embodying our invention, at least three primary colors are required to make a full color display. Although more than three colors may be used to produce colors of the desired hues, the use of more than three colors may

complicate the spot projection and scanning subsystems and may add only a very small range of potential hues not available using just three colors. It is also most likely that all video formats would be in a three-color format, and this signal would have to be converted to a four or more color format, introducing additional processing requirements.

Laser Section - Quality of Beams

The light output of the lasers to be used in our preferred theater application should preferably be in or near TEM00 in transverse mode, and must either be continuous wave or pulsed at a very fast rate. Of the common pulse generation techniques, mode-locking produces a train of evenly spaced pulses at 70 to 200 (or more) million pulses per second, and may be used in our invention. However, within our invention, any laser whatever may be used, as long as it meets beam quality, pulsing, color, and power requirements.

Laser Section - Configurations

We prefer to employ diode-pumped solid state (DPSS) lasers for reasons of economy, reliability, size, packaging considerations and infrastructure requirements. DPSS lasers have been commercially available since the late 1980's, although visible DPSS lasers in the colors and power range required for preferred embodiments of our laser projection system 10 are just now being developed. However, we also anticipate the possibility that Argon and Krypton ion, flowing jet dye, semiconductor, diode, or any other suitable lasers could be used to advantage. Optical fiber lasers, i.e., lasers wherein the optical fiber itself is the lasing material, with improvement could also be used. Fiber lasers could be particularly useful with our invention if they could be internally modulated, so as to replace both the laser and modulation sections.

The ability to combine multiple lasers to produce an image on a large screen 12 of acceptable brightness illustrates another advantage of our invention. When attempting the use of multiple lasers prior to our invention, elaborate, complicated and expensive arrays of mirrors and lenses were required to combine

beams from separate lasers for projection onto a screen 12. However, with the projection of multiple beams with the emitting ends of our invention, multiple lasers having reduced power in comparison to the total power needed to provide acceptable brightness can be combined to advantage. Each laser unit should produce a beam of sufficient quality for insertion into a 8.5 micron optical fiber with at least 85% efficiency, with very low insertion loss variation.

Referring again to FIG. 17, the beam from each laser 22, 24, 26 would be divided by staged beam splitters 28 as shown in FIG. 17 into four separate beams each, which as described above are separately directed to the modulators 32. Specifically, the beam from laser 22 is split into four red beams by the dividers 28, which are directed to modulators 32; the beam from laser 24 is split into four green beams by the dividers 28, which are directed to modulators 32; and the beam from laser 26 is split into four blue beams by the dividers 28, which are directed to modulators 32. The beams from the modulators 32 are respectively directed to the input lenses 48 for insertion into the insertion ends 44 of the fibers 42. In FIG. 17 subscripts are used in the designation of the individual fibers 42 wherein the first subscript delineates the color (r=red, g=green, b=blue) and the second subscript delineates the row location of the associated emitting end; thus 42gC would be the green fiber for row C.

Referring to FIG. 18, an alternate laser section configuration for use with the 4 row by 6 spots per row output head configuration shown in FIG. 8, would preferably employ a Millennia 10 watt green DPSS laser 22 manufactured by Spectra Physics Lasers, Inc. pumping a model 375 dye laser 22A also manufactured by Spectra Physics Lasers, Inc. for producing the red laser beam, split into four beams with beam splitters 28 for insertion into the fibers 42. Such an alternative laser section could further use a Millennia 5 watt green DPSS laser 24 manufactured by Spectra Physics Lasers, Inc. for producing the green laser beam, split into four green beams with beam splitters 28 for insertion into the fibers 42, and sixteen blue DPSS

lasers, model 58BLD605 manufactured by Melles-Griot, mounted to respectively insert the blue beam from each blue laser 26 directly into the insertion end 44 of the remaining sixteen fibers 42.

A variety of possible combinations of the blue beams may be employed to produce the desired intensity of blue at a specific dot location in the line. In our preferred system illustrated previously in FIG. 1 and in Example 9 later herein, we prefer to modulate all four blue beams within a particular row at one-fourth the required aggregate intensity. An alternative system could modulate one or more blue beams at full intensity, and modulate a remaining blue beam at the differential intensity to produce the required total intensity after time combining of the modulated beams.

FIG. 19 shows the use of twelve separate lasers 222, 224 and 226 to produce the respective red, green and blue beams independently respectively inserted through modulators 42 and input lenses 48 into each fiber 42 to emit from the output head of FIG. 5 a 4 row by 3 spots per row pattern of spots shown in FIG. 5S. This laser configuration could be employed if reasonable lower power lasers were available to produce each color instead of more expensive, more powerful lasers needed to produce beams split into multiple beams for insertion into the fibers.

It will be apparent that the use of fiber and multi-line scanning alone or in combination with either time combination or fiber-based beam coupling provides wondrous flexibility in the configuration of the laser section and the selection of the lasers for use therein. Subject to constraints noted previously, such as beam quality, power levels within the modulators and at the point of insertion of the individual laser beams into fibers, any of a number of lasers and laser configurations can be employed to advantage within our invention to create the required total laser power. Further, as shown later herein in connection with FIGs. 20 -25, only minor modifications to the modulation, spot projection and controller sections 30, 40 and 100,

respectively, are needed to implement these alternative configurations.

In summary, a variety of lasers and laser configurations may be used to generate the total laser power required of red, green and blue, including, without limitation, RGB lasers that generate red, green and blue beams from a single laser, lasers that each produce the total power required of one of red, green and blue, one laser of each color per line, and multiple lasers per color per line, either through expansion of the output head (as described above) or through use of fiber-based beam coupling either before or after modulation.

Controller Section

FIG. 26 shows a block diagram of the controller section 100 of the first embodiment of our preferred theater laser projection system 10. The controller section 100 receives the video input, processes and presents the image data to the scanning and modulation components, and controls the overall operation of the projection system.

The controller section 100 has two functional areas, the scanning control section 102 and the image control section 120. The image control section 120 handles all of the functions directly related to acquiring the source image data and processing it for delivery to the modulator section 30, as well as sending certain signals, including synchronization signals, to the scanning control section 102. The scanning control section 102 performs all other control and operational requirements, including, most particularly, control of the components of the scanning section 70, providing certain data and signals to the image control section 120 particularly during initialization, receiving and executing all external commands, such as from the operator terminal of a theater control system, and providing data to such external systems or terminals, including diagnostics and record-keeping.

The scanning control section 102 includes a control microprocessor 104 that controls operation of the other components of the scanning system control section 102, interfaces

with external terminals and systems, manages safety and start-up inter-locks, and routes or processes certain signals for the use by the image control section 120. The scanning control section 102 also includes a vertical facet error correction function.

The scanning control section 102 further includes the galvanometer position control function. The galvanometer is controlled by providing position signals to the galvanometer driver which correspond to a vertical traverse of the screen 12 at a rate appropriate to the frame rate and desired image format. Based upon a signal from the image control section that a complete frame has been written, this function also causes the galvanometer controller 87 to return the galvanometer mirror 84 to where it is in position to begin scanning the next frame.

The scanning control section 102 also controls the speed of the polygon mirror 74 by signals to the polygon mirror controller 80. An initial signal corresponding to the desired output scan rate is sent to the driver by the microprocessor 104 and updated thereafter based upon signals from the output pixel clock and line and frame timing subsection 122 (described in more detail later herein) of the image control section 120. Externally, dynamic adjustments are made by a feedback loop within the polygon mirror controller 80 based on the feedback of the "facet pulse", which has been described elsewhere herein for its additional use in delaying the release of a line of image data until the active facet is in the correct position.

The scanning control section 102 also initiates all start-up, shut down and emergency procedures, as well as managing all necessary interlocks. Start-up functions include initializing all data tables, including those in the image control section 120, ensuring that all scanning components are in position to make the first scan pass and identifying for the image control section key parameters related to the source image data, e.g., format and frame rate,. and the desired image output.

The image control section 120 receives image data signals, both analog and digital, in a variety of formats and processes the data as necessary to create analog signals for the individual

modulator controllers 34 to scan the images in the desired resolution and format. This may include changing the frame rate as well. The image control section 120 also provides horizontal and vertical synchronization signals to the scanning control section 102 which are used, among other purposes, for controlling polygon speed.

Our preferred embodiment will accept image data signals of at least the following types and formats: parallel digital, RGBHV (similar to the XVGA format of computer monitors) and other analog signals, serial digital (such as SMPTE 292), and HDTV, each in both interlaced and progressive formats.

The input decode, decrypt and decompress subsection 128 converts all input image data into uncompressed, decrypted "parallel digital" data. In the case of analog data this is accomplished by an analog to digital converter, perhaps after decoding, depending upon format. In the case of digital input this involves decompression, decryption and "decoding" (conversion) if the data is serial and not parallel. In our preferred embodiment decompression will be done external to our projection system. Decryption of various standard encryption formats will be done by the input decode, decrypt and decompress subsection 128 using widely available or licensed commercial algorithms. The image data leaving the input decode, decrypt and decompress subsection 128 will retain certain of its original characteristics, such as pixel count and rate, line count and rate, frame rate and aspect ratio.

The image scaler 130 takes the parallel digital output of the input decode, decrypt and decompress subsection 128 and reformats it to the desired line rate, line count, pixel count, pixel rate, frame rate and aspect ratio in a manner familiar to one skilled in the art of video electronics. Further, the image scaler also generates a timing signal for use in outputting the reformatted image data to the modulator controllers 34 in the form of a "pixel clock", as well as horizontal and vertical synchronization pulses. The "new" pixel clock and horizontal synchronization pulses are modified by pixel clock divider 124

and the output pixel clock and line and frame timing subsection 122, respectively, to reflect the simultaneous scanning of multiple lines.

The image data leaving the image scaler 130 now enters the buffer loading sequencer 132 which distributes the image pixel data by color and line to buffers or FIFOs 134 to accomplish the reordering and time delays as required for the particular emitting end configuration of the output head 58. In our preferred embodiment having an emitting end configuration of four rows by three emitting ends per row, there would be twelve separate buffers, with the data corresponding to all the red values for each pixel in the line to be scanned in the next scan pass by the upper-most row of emitting ends, or bottom-most row of spots of the corresponding spot pattern, being loaded into buffer 134, the data corresponding to all the green values being loaded into buffer 134, and the data corresponding to all the blue value being loaded into buffer 134. The values for the line to be scanned in that scan pass by the next-to-upper-most row of emitting ends, or the next-to-bottom-most row of spots of the corresponding spot pattern, will similarly be loaded into buffers 134. Similarly for the lines to be scanned by the other two rows of the emitting end configuration, the appropriate values for each row will be loaded into buffers 134. This loading of the buffers is performed by a "sequencer" which in our preferred embodiment may be incorporated in a programmable gate array. Recall that the first scan passes at least one row of emitting ends, and therefore spots, will be blanked. In our preferred embodiment this will be accomplished by time delays for the lines to be blanked.

Each buffer 134 is uniquely associated with a modulator 32 and its associated modulator controller 34 and with a fiber emitting end 56. For example, buffer 134 would be associated with modulator 32 and its modulator controller 34 schematically shown in FIG. 26, and buffer 134 would be associated with modulator 32 and its modulator controller 34. Each buffer 134 also has a programmed time delay associated with it and its eventual output

to the modulator and fiber. Each delay is necessary to scan the reformatted data into the desired image, measured in either full or partial pixel counts to accomplish time combining and is implemented within each of the output counter and controller 136. In many emitting head configurations, as will be described herein, this delay may be as long as several lines of pixels. Each buffer 134 also has its own output counter and controller 136 and digital-to-analog converter 138.

Once the output of a line of buffer data is triggered by a facet pulse, the output continues for each buffer of a given line until all of the pixels for that line are displayed. Each modulator controller 34 is signaled to reset its modulator 32 to black, until the next scan pass is ready.

Lastly, in subsection 138, color corrections are applied, preferably by means of a color look-up table, the function of which is familiar to one skilled in the art, and the digital data is converted to an analog signal suitable for use by the modulator controllers that we prefer.

<u>Alternate Spot Patterns and Consequent Differences in Reordering and Time Combination</u>

The foregoing descriptions of the spot projection, scanning and controller sections 40, 70 and 100, respectively, of the first embodiment have assumed an output head 58 having a 4 x 3 emitting end 56 configuration projecting a 4 row by 3 spots per row spot pattern. This configuration is the one preferred for the commercial versions of our theater laser projection system 10. However, the following alternate embodiments of these sections describe different configurations, and the advantages derived therefrom.

As noted previously, an output head according to our invention is not limited to four rows of emitting ends, and encompasses five or more, or three or less, rows of emitting ends. Five rows of emitting ends will write five lines per scan pass, reducing the number of scan passes required per frame for the same image and resolution as discussed with the four row embodiment, with advantages in increased degree similar to those

described for the first embodiment, but at the increased expense of additional modulators, lasers and/or splitters. As noted elsewhere, five rows can also be used to increase resolution. Three rows of emitting ends, while again straightforward, will result in a lesser expense, primarily by avoiding the inclusion of expensive modulators and splitters and perhaps lasers, but will realize the advantages of the first embodiment to a lesser degree. The pattern of spots resulting from these different output head configurations or emitting end arrays must be taken into consideration when determining how to reorder the image data.

Description of Examples of Alternate Spot Patterns

In the description of each of the following Examples 1-21, for the sake of conciseness and clarity, we have included Tables EX-1 through Tables EX-21 in lieu of detailed textual description of the timing and location of the reordering of lines during frame scanning based on the number of, and the relative effective spacing of, the rows of spots projected on the screen, and/or of the time combining of spots at dot locations during line scanning based on the number of, and the relative effective dot spacing of, the spots projected on the screen. These Tables EX-1 through EX-21 include a listing of the assumed number of rows, number of spots per row, special configurations involving more than one spot of a particular color, or a special arrangement of color positions in the array, and the relevant Figures. The body of each Table includes values for scan pass "s" during frame scanning or time "t" during line scanning or between the beginning of scan passes, the number of the line or dot location on the screen, the row identification (e.g., AAA, BBB, CCC, DDD or AAAA, BBBB, CCCC, DDDD et seq.) or spot color (R,G,B) corresponding to the time written and location on the screen, and whether the row of spots or spot in a row is activated or blanked ("b"). The following Table EX indexes pertinent parameters for each of the examples, where the vertical adjustment for each embodiment, except as noted in the Description column, is assumed

to be equal to the number of rows of spots projected on the screen.

The physical distance between emitting ends, and therefore the physical distance between rows of spots on the screen remains constant, despite changes in aspect ratio or resolution. However, changes in throw distance, aspect ratio and/or resolution may alter the effective row spacing, or number of lines of dots between rows of spots projected on the screen, and the effective spot spacing, or number of dot locations between spots within a row of spots. Therefore, It should be kept in mind while considering the disclosure appearing herein that a preferred resolution of 1920x1080p and aspect ratio of 16:9 are assumed for the sake of simplicity and convenience. However, the principles of our invention, and its adaptation to different resolutions and aspect ratios, remain applicable for innumerable different combinations and permutations of different variables of projection systems.

One can infer from the foregoing that only certain line spacings would be acceptable given a screen size and desired line configuration. For example, if the image is to have 1080 lines vertically spaced over the full height of a theater screen that is 18 feet tall, the spacing of the dot locations would be about 0.2 inches. Assuming that the actual spacing between rows of the pattern of spots on the screen is 2.28 inches given the preferred throw distance, this would result in an effective row spacing of 11.4, which is not an appropriate multiple of the line spacing on the screen. One could preferably move the projector closer or further from the screen (or adjust a prescan zoom output lens or select a different fixed output lens) so that the effective row spacing is appropriate, such as 11.0 or 12.0, respectively, for the example, and then adjust the galvanometer frame sweep or adjustment so that the 1080 lines again fills the screen. I n the 4 row by 3 emitting ends per row arrangement shown in FIG. 5, as stated previously, an effective row spacing as close as the five lines assumed for the preferred embodiment in actual practice may not be feasible at this time. In actual practice,

we have determined that the closest effective row spacing physically possible without custom configurations of the fiber cladding, using a single lens to focus the beams onto the screen 12 through the facets 76 of the polygon mirror 74, could be more than 10 lines, or even more in other configurations. At present levels of technology, closer spot spacings are not feasible for our application. However, after numerous examples illustrating the effect of these different effective row spacings and output head configurations of emitting ends, we describe several possible implementations of our conception that may enable closer effective row spacing. For each of the following examples, all system sections and components are the same as with the preferred embodiment of FIG. 1, except for the output head 58 (spot pattern) configuration and the consequent different reordering performed by the controller section 100, and possible addition of fiber combiners.

For reasons more fully described below, for each of these examples the effective row spacing of the scanned lines must not be an exact multiple of the number of rows of emitting ends in the output head 58 array. While it is a basic goal and assumption that each line is written by all colors exactly once, there are useful exceptions, one of which appears in EXAMPLE 9 below.

TABLE EX

Example Number	Rows x Spots perRow	Effective RowSpacing	Description	Tables	FIGs.
1	4/3	3	Log Spot Pattern	EX-1	27-8
2	4/3	4	IneffectiveRowSpacing	EX-2	29
3	4/3	4	IneffectiveRowSpacing (5 LineVerticalAdjstmt)	EX-3	30
4	4/3	49	LargeFiberOutputHead	EX-4	32
5	3/3	4	Brick Spot Pattern	EX-5	38,39
6	2/3	9	Brick Spot Pattern	EX-6	35,36
7	4/3	11-10-13	Unequal Row Spacing	EX-7	27,37
8	5/3	6	Brick Spot Pattern	EX-8	38,39
9	4/6	11	4red,4green,16blue spots 3 spot spacing w/I row	EX-9	40-42
10	4/3	5	Misalignment w/I row	--	43
11	4/3	4	NonuniformSpcng w/I row	EX-11	44-46
12	4/3	1	Step Spot Pattern	EX-12	47-49
13	4/3	~1	Linear Spot Pattern	--	50-51
14	4/3	~1	Linear Spot Pattern w/ modified emitting ends	--	52-53
15	12/1	1	Ramp Configuration in 4 RGB Groups	EX-15	54-57
16	12/1	1	Ramp Spot Pattern in RRRR-GGGG-BBBB Groups	EX-16	58-61
17	12/1	1	Ramp Interlaced	EX-17	63,64
18	4/3	9	Log Interlaced	EX-18	65,66
19	4/3	10	Log Interlaced	EX-19	67,68
20	3/12	1	Three Ramp	EX-20	69,70
21	4/1	1	Ramp Configuration w/ Composite Beams	EX-21	67,71

EXAMPLE 1

Example 1 illustrates reordering of the video signal to scan complete frames with an emitting end array shown in FIG. 27 and a corresponding spot pattern shown in FIG. 27S of 4 rows by 3 spots per row in a "log" configuration, with the assumptions shown in Tables EX-1A through EX-1C. FIGs. 28A-28H and Table EX-

1A describe the lines written at each scan pass s1, s2, s3,.... We further assume a uniform or equal physical distance between rows of emitting ends in the output head 58, which is not necessarily required, as described later in connection with other examples. Further, for FIGs. 28A-28H lines written by RowD, RowC, RowB, RowA of emitting ends are indicated by DDDD, CCCC, BBBB, AAAA, respectively.

For this Example 1, as shown by FIGs. 28A through 28D and described in Table EX-1A, the effective row spacing of 3 lines writes the first four lines of the frame during scan passes s1, s2 and s3 in a 4,1,2,3 order. FIGs. 28E through 28H show and Table EX-1A describes the reordering of the pixel information to write lines at the bottom of the frame during scan passes s269-s272 and thereafter, with appropriate blanking of rows when out-of-frame. Thus, for the spot pattern of Example 1, having an effective row spacing of 3 lines, a complete frame is written in 272 scan passes. In the emitting end array shown in FIG. 5 and the resulting spot pattern shown in FIG. 5S, the emitting ends and consequently the pattern of spots of the rows are horizontally centered on the emitting end in the row above and/or below, referred to herein as a "rectangular" or "brick" array or pattern. In such a pattern, during each scan pass, the right-most spots of all rows of the rectangular spot pattern will write the first dot locations in their respective lines, as shown in FIGs. 13A-13E, at approximately the same time.

TABLE EX-1A

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 27,28 Vertical Adjustment: 4 lines
Effective Row Spacing: 3 lines

Scan Pass	Lines Written by Respective Rows of Emitting Ends			
	RowA	RowB	RowC	RowD
1	b	b	1	4
2	b	2	5	8
3	3	6	9	12
4	7	10	13	16
5	11	14	17	20
:	:	:	:	:
270	1071	1074	1077	1080
271	1075	1078	b	b
272	1079	b	b	b

However, FIG.27 shows a different arrangement, in which the emitting ends, and therefore the spots, in each row are offset such that the emitting ends and spots in alternate rows fit in the valleys between the obverse rows, termed herein for convenience the "log" array or pattern, as shown in FIGs. 27 and 27s. As shown in FIG. 28 and Table EX-1B for the 4 row by 3 spots per row pattern of spots of this Example 1 with the log pattern, and assuming a spacing between spots within rows of 4 dot locations, at time t1 during scan pass s3, dot location 1 in lines L6 and L12 will be illuminated by the red spots of RowB and RowD while the green and blue spots of RowB and RowD, and all spots of RowA and RowC will be blanked. As shown by FIGs. 31B through 31F and described in Table EX-1B, for the remaining times t2-t11 of the illustrative scan pass s3, at time t11 all spots will illuminate dot locations at an appropriately modulated intensity (which may be zero). It should be noted that the color spots need not be in the same order for all rows, as will be described in more detail herein. Table EX-1C illustrates the timing of the dot illumination for scan pass s3 for times t1920-1930 at the end of the line and scan pass prior to initiating the next scan pass s4 shown in FIG. 28D.

TABLE EX-1B

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figures: FIGs. 28,30 Vertical Adjustment: 4 lines
Pattern of Spots: Log Effective Row Spacing(all rows): 3 lines
Scan Pass: 3 Blank=b Spot Spacing within Row: 4 dots

	RowA			RowB			RowC			RowD		
	Blue	Grn	Red	Blue	Grn	Red	Blue	Grn	Red	Blue	Grn	Red
Line	time t1			Dot Locations								
3	b	b	b									
6				b	b	1						
9							b	b	b			
12										b	b	1
Line	time t2			Dot Locations								
3	b	b	b									
6				b	b	2						
9							b	b	b			
12										b	b	2
Line	time t3			Dot Locations								
3	b	b	1									
6				b	b	3						
9							b	b	1			
12										b	b	3
Line	time t5			Dot Locations								
3	b	b	3									
6				b	1	5						
9							b	b	3			
12										b	1	5
Line	time t11			Dot Locations								
3	1	5	9									
6				3	7	11						
9							1	5	9			
12										3	7	11

TABLE EX-1C

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figures: FIGs. 27,31 Vertical Adjustment: 4 lines
Pattern of Spots: Log Effective Row Spacing(all rows): 3 lines
Scan Pass: 3 Blank=b Spot Spacing within Row: 4 dots

	RowA			RowB			RowC			RowD		
	Blue	Grn	Red	Blue	Grn	Red	Blue	Grn	Red	Blue	Grn	Red
Line	time t1920						Dot Locations					
3	1910	1914	1918									
6				1912	1916	1920						
9							1910	1914	1918			
12										1912	1916	1920
Line	time t1921						Dot Locations					
3	1911	1915	1919									
6				1913	1917	b						
9							1911	1915	1919			
12										1913	1917	b
Line	time t1922						Dot Locations					
3	1912	1916	1920									
6				1914	1918	b						
9							1912	1916	1920			
12										1914	1918	b
Line	time t1924						Dot Locations					
3	1914	1918	b									
6				1916	1920	b						
9							1914	1918	b			
12										1916	1920	b
Line	time t1930						Dot Locations					
3	1920	b	b									
6				b	b	b						
9							1920	b	b			
12										b	b	b

EXAMPLE 2

Example 2, described in Table EX-2 below and schematically shown in FIGs. 5S, 29A through 29D is an example of how an effective row spacing that is an even multiple of the number of rows of emitting ends or spots (in this Example 2, an effective row spacing of 4) with a vertical line adjustment between scan

passes equal to the number of rows of emitting ends or spots (in this Example 2, a vertical adjustment of 4 lines) is not effective in the exemplary system. Referring to Table EX-2 and FIGs. 29A-29D, it may be seen that lines L1, L2 and L3; L5, L6, L7; L9, L10, L11; and so forth will not be written during a top to bottom series of scan passes.

EXAMPLE 3

Similarly, in Example 3, described in Table EX-3 and schematically shown in a typical frame format in FIGs. 30A through 30D it may be seen that changing the line adjustment for the four line effective row spacing output head to a five line adjustment still fails to write lines 3, 8, ..., etc.

EXAMPLE 4

Various effective row spacings for the emitting end configurations and spot patterns of the foregoing Examples 1-3 can be used. For this Example 4, described in Table EX-4 and schematically shown in a preferred 1920x1080p frame in FIGs. 27A-27H, we assume an effective row spot spacing of about 49 lines, but not 48 lines, because this would be an even multiple of the number of rows of spots projected from the array of emitting ends onto the screen and thus would not be effective in writing all lines of the frame. It should be noted that in Example 4, the lines are written in a 4,3,2,1 sequence, as opposed to the different order from Example 1 of 4,1,2,3. As with previous examples, line L4 of the frame is preferably first written with the bottom row RowD of spots, corresponding to the top row RowD of emitting ends of the output head, and as shown in FIGs. 32A-32H and described in Table EX-4, lines L1-L4 will be written after 37 scan passes. For this Example 4, and as shown in Table EX-4, based on the assumed 1920x1080p resolution, after the 270 scans required to move row RowD down to write line L1080, thirty-six additional scans will occur as row RowA is moved down the screen 12 to write line L1077.

TABLE EX-2

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 29 Vertical Adjustment: 4 lines
Effective Row Spacing: 4 lines

Scan Pass	Lines Written by Respective Rows of Emitting Ends			
	RowA	RowB	RowC	RowD
1	b	b	b	4
2	b	b	4	8
3	b	4	8	12
4	4	8	12	16
5	8	12	16	20
:	:	:	:	:
270	1068	1072	1076	1080
271	1072	1076	1080	b
272	1076	1080	b	b

TABLE EX-3

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 30 Vertical Adjustment: 5 lines
Effective Row Spacing: 4 lines

Scan Pass	Lines Written by Respective Rows of Emitting Ends			
	RowA	RowB	RowC	RowD
1	b	b	b	4
2	b	1	5	9
3	2	6	10	14
4	7	11	15	19
5	12	16	20	24
:	:	:	:	:
216	1067	1071	1075	1079
217	1072	1076	1080	b
218	1077	b	b	b

TABLE EX-4

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 32 Vertical Adjustment: 4 lines
Effective Row Spacing: 49 lines

Scan Pass	Lines Written by Respective Rows of Emitting Ends			
	RowA	RowB	RowC	RowD
1	b	b	b	4
2	b	b	b	8
3	b	b	b	12
⋮	⋮	⋮	⋮	⋮
13	b	b	3	52
14	b	b	7	56
⋮	⋮	⋮	⋮	⋮
25	b	2	51	100
26	b	6	55	104
⋮	⋮	⋮	⋮	⋮
37	1	50	99	148
38	5	54	103	152
⋮	⋮	⋮	⋮	⋮
270	933	982	1031	1080
271	937	986	1035	b
⋮	⋮	⋮	⋮	⋮
282	981	1030	1079	b
283	985	1034	b	b
⋮	⋮	⋮	⋮	⋮
294	1029	1078	b	b
295	1033	b	b	b
⋮	⋮	⋮	⋮	⋮
306	1077	b	b	b

EXAMPLES 5-16

The next examples (Examples 5-16) illustrate variations of emitting end (spot pattern) configurations of the output head from the 4x3 array described for Examples 1-4, in which FIGs. 38-61 and Tables EX-5 through EX-16 show and describe the reordering of the video signal required for a variety of different output head (pattern of spots) configurations.

Unlike Examples 1-4, the following Examples 5-16 are not limited to a 4 row by 3 spots per row spot pattern or corresponding emitting end array, a 4 line vertical adjustment after each horizontal scan pass, a uniform distance between rows of emitting ends, the assumption of three emitting ends in each row emitting one of the three primary colors, or even vertical alignment of spots in different rows.

For convenient reference as to the following examples, we continue to refer to the rows of the pattern of spots from top to bottom, e.g., rows RowA, RowB, RowC, RowD, RowE, for the 5x3 array. As with the previous examples, the lines of spots written by each respective row are denoted in the drawings by a row of letters corresponding to that row (e.g., AAA, BBB, CCC, DDD and EEE or AAAA, BBBB, CCCC, DDDD and EEEE). For all of the Examples 5-16, all system sections and components are the same as with the preferred embodiment of FIG. 1, except for the output head 58 configuration and resulting spot pattern, and the consequent different reordering performed by the controller section 100, or as specifically noted for the particular example concerned.

EXAMPLE 5

In the proposed commercial version of a theater laser projection system according to our invention, similar to the preferred embodiment described hereinbefore, a 4 row by 3 spots per row spot pattern is identified as the best compromise between the enhanced resolution available by dividing the number of lines per frame by four and other benefits during line scanning, and the increased cost and complexity of scanning four lines per scan pass. A next preferred embodiment, exemplified by Example 5, is an output head having 9 fibers arranged in 3 rows of 3 emitting ends, producing a spot pattern of three vertically spaced apart rows of red, green and blue spots as shown in FIGs. 33 and 33S. Although the 3x3 spot pattern of Examples 5 require 360 scan passes per frame, rather than 270 scan passes per frame for the 4x3 spot pattern examples, the expense of beam dividing optics, modulators, other components and perhaps lasers is reduced. Further, although approaching the practical limits of our preferred polygon mirror, at least for the preferred 1920x1080p resolution, this output head configuration is also preferred.

Example 5, as shown in FIG. 34 and described in Table 5, illustrates the reordering required for a 3 row by 3 emitting end per row output head configuration and spot pattern, respectively, shown in FIGs. 33 and 33S, wherein the vertical adjustment between scan passes is 3 lines of dot locations. As with most of

the examples, for Example 5 the vertical adjustment preferably equals the number of rows of emitting ends in the output head for these cases. Although we have not provided as many examples of the reordering required for this output head configuration as for the 4 row by 3 emitting end per row configuration in Examples 1-4, similar alternatives, and many others, can be deduced by extrapolating the examples described herein.

TABLE EX-5

Output Head Configuration (spot pattern)- Rows: 3 Spots/Row: 3
Corresponding Figure: FIG. 33 Vertical Adjustment: 3 lines
Effective Row Spacing(all rows): 4 lines

	Lines Written by Respective Rows of Emitting Ends		
Scan Pass	RowA	RowB	RowC
1	b	b	3
2	b	2	6
3	1	5	9
4	4	8	12
:	:	:	:
359	1069	1073	1077
360	1072	1076	1080
361	1075	1079	b
362	1078	b	b

For Example 5, shown in FIGs. 34A-34H and described in Table EX-5, we assume an effective row spacing of about 4 lines between RowA, RowB and RowC. Referring to FIG. 34A, at time t1, line L3 of the frame is preferably first written with the bottom row RowC of the pattern of spots projected on the screen by the emitting ends of the output head, while RowA and RowB are blanked. As shown in FIGs. 34B-34D, successive scan passes s2, s3 and s4 will write lines L1-L3, and as shown in FIGs. 34E-34H all lines of the frame will be written after 362 scan passes. Note that with this odd number of rows of this Example 5, an even effective row spacing is effective in writing all lines, whereas for the prior examples of an even number of rows, an even effective row spacing is not effective.

EXAMPLE 6

Example 6 illustrates a two row by three emitting ends per row array of emitting ends, shown in FIG. 35, projecting a two row by three spots per row pattern of spots on the screen shown in FIG. 35S. In Example 6, FIGs. 36A-36H and Table EX-6 illustrate the reordering required for a 2 row by 3 emitting end per row output head configuration wherein the vertical adjustment between scan passes is two lines, where as with most of the examples, the vertical adjustment equals the number of rows of emitting ends in the output head for these cases. For Example 6, shown in FIG. 36H and described in Table EX-6, we assume an effective row spacing of about 9 lines between each RowA and RowB. Referring to FIG. 36A, at scan pass s1, line L2 of the frame is preferably first written with the bottom row RowB of the pattern of spots projected on the screen by the emitting ends of the output head, while RowA is blanked. Referring to FIGs. 36B-36D, lines L1-L2 will be written after 5 scan passes, and as shown in FIGs. 36E-36H all lines of the frame will be written in 544 scan passes.

EXAMPLE 7

Example 7 illustrates the reordering required for a 4 row by 3 spots per row pattern of spots, similar to that of FIG. 27S, projected by an output head configuration wherein the effective row spacing is not uniform. It should be understood that an almost unlimited number of different output head emitting end configurations and patterns of spots are possible, Example 7 being merely intended to hint at the myriad possible configurations enabled by our invention. Although a corresponding output head configuration is not included in the drawings, for Example 7, Table EX-7 describes and FIGs. 37A-37H graphically illustrate, the reordering that is required for an effective row spacing of about 11 lines between RowA and RowB, of about 10 lines between RowB and RowC, and of about 13 lines between RowC and RowD with four line vertical adjustments. Referring to FIG. 37A, although not required, line L4 of the frame is preferably first written at scan pass s1 with the bottom

row RowD of the pattern of spots. As shown in FIGs. 37B-37H, and described in Table EX-7, lines L1-L4 all will be written after 9 horizontal scans have occurred, and 278 scan passes will be required to write a complete frame.

TABLE EX-6

Spot Pattern-Rows:2 Spots/Row:3
Corresponding Figure: FIG. 36
Vertical Adjustment: 2 lines
Effective Row Spacing: 9 lines

	Lines Written by Row	
Scan Pass	RowA	RowB
1	b	2
2	b	4
⋮	⋮	⋮
4	b	8
5	1	10
6	3	12
⋮	⋮	⋮
539	1069	1078
540	1071	1080
541	1073	b
⋮	⋮	⋮
543	1077	b
544	1079	b

EXAMPLE 8

Example 8 illustrates the reordering required for a 5 row by 3 emitting end per row output head configuration shown in FIG. 38 projecting the spot pattern shown in FIG. 38S, wherein the effective row spacing between rows of the pattern of spots projected by the emitting ends through the scanning section onto the screen is uniform. For these examples, we assume a vertical adjustment between horizontal scans of about 5 lines, where although not required for utilizing our invention, and as with most of the foregoing examples, the vertical adjustment equals the number of rows of emitting ends in the output head. Although we have not provided as many examples of the reordering required for this output head configuration as for the 4 row by 3 emitting

end per row configuration, similar examples can be deduced by extrapolating the examples herein.

TABLE EX-7

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 37 Vertical Adjustment: 4 lines
Effective Row Spacing(RowA-RowB): 11 lines
(RowB-RowC): 10 lines
(RowC-RowD): 13 lines

	Lines Written by Respective Rows of Emitting Ends			
Scan Pass	RowA	RowB	RowC	RowD
1	b	b	b	4
2	b	b	b	8
⋮	⋮	⋮	⋮	⋮
4	b	b	3	16
5	b	b	7	20
6	b	1	11	24
7	b	5	15	28
⋮	⋮	⋮	⋮	⋮
9	2	13	23	36
10	6	17	27	40
⋮	⋮	⋮	⋮	⋮
270	1046	1057	1067	1080
271	1050	1061	1071	b
⋮	⋮	⋮	⋮	⋮
273	1058	1069	1079	b
274	1062	1073	b	b
275	1066	1077	b	b
276	1070	b	b	b
277	1074	b	b	b
278	1078	b	b	b

For Example 8, Table EX-8 describes and FIGs. 39A-39J graphically illustrates, the reordering necessitated by an effective row spacing of about 6 lines between RowA, RowB, RowC, RowD and RowE. Although not required, at scan pass s1, line L5 of the frame is preferably first written with the bottom row RowE of the pattern of spots, while RowA, RowB, RowC and RowD are blanked. As shown in FIGs. 39A-39J, lines L1-L4 all will be written after 5 horizontal scan passes have occurred, and as shown in FIGs. 39F-39J, 220 scan passes will be required to write a complete frame.

TABLE EX-8

Output Head Configuration (spot pattern)- Rows: 5 Spots/Row: 3
Corresponding Figures: FIGs. 38-39 Vertical Adjustment: 5 lines
Effective Row Spacing(all rows): 6 lines

Scan Pass	Lines Written by Respective Rows of Emitting Ends				
	RowA	RowB	RowC	RowD	RowE
1	b	b	b	b	5
2	b	b	b	4	10
3	b	b	3	9	15
4	b	2	8	14	20
5	1	7	13	19	25
:	:	:	:	:	:
216	1056	1062	1068	1074	1080
217	1061	1067	1073	1079	b
218	1066	1072	1078	b	b
219	1071	1077	b	b	b
220	1076	b	b	b	b

EXAMPLES 9-15

It should be understood that an almost unlimited number of different output head emitting end configurations are possible, including those already illustrated above for 2, 3, 4 and 5 row, and for more than five row arrays of the output head. However, of the many possibilities, several configurations are of particular interest, as described in connection with the following further examples.

EXAMPLE 9

Example 9, shown in FIGs. 40, 40S, 41 and 42, and further described in Table EX-9, illustrates the reordering required for an output head configuration wherein each row has more than three emitting ends. This Example is an exception to the previously stated rule that all lines should be written by each color exactly once, in that we write one color, in this case blue, with four emitting ends per line. The 4x6 output head array illustrated in Example 19 is schematically shown in FIG. 40 and the corresponding spot pattern is shown in FIG. 40S. FIG. 18 schematically shows a system configuration which may employ this

head configuration of Example 9 to advantage. Instead of a system wherein a single laser for generating each of the primary colors is split into four beams for insertion into one of the fibers in each row as shown in FIG. 17, or where individual lasers are employed for the beams inserted into each fiber as shown in FIG. 19, in this embodiment shown in FIG. 18, a single laser each is used to generate the red and green laser beams that are split with splitters into four red and four green beams, and four blue lasers are used for each row, or 16 blue lasers in total to generate the entire spot pattern of 4 rows of 6 spots per row shown in FIG. 40S. A laser projection system according to our invention enables the convenient and efficient use of multiple lasers to scan each line of a frame with a particular color. It may be that multiple blue lasers for each line will be more economical, and produce better quality beams than four more powerful lasers, or a single very powerful laser that is split into four beams.

As previously described, for this Example 9, graphically shown in FIGs. 41A-41F and 42A-42F, and further described in Table EX-9, we assume a 4 row output head array having six emitting ends per row, including one emitting a red beam, one emitting a green beam, and four emitting blue beams. The beam from each emitting end in a row strikes each dot location in an appropriate line on the screen in the spot pattern shown in FIG. 40S. Because the beams strike the screen within one microsecond (1 μs), the total power of the four blue beams emitted from a particular row of emitting ends directed to each dot location is visualized by the audience as though a single beam of the total power required is utilized, as in the system shown in FIG. 1. and the pattern of spots shown in FIGs. 5S or 27S. In assigning the color value from the lookup table, the controller section may either modulate the blue beams equally or unequally as desired to produce the desired aggregate color intensity specified in the video data at the corresponding dot location on the screen.

TABLE EX-9

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 6
Corresponding Figures: FIG. 40-42 Vertical Adjustment: 4 lines
Effective Row spacing within Row(all spots): 3 spots

time t	Left to Right Dot Locations Written by Respective Spots					
	blue-z●	blue-y⚲	blue-x⏀	blue-w○	green+	red×
1	b	b	b	b	b	1
2 : 4	b : b	b : b	b : b	b : b	b : 1	2 : 4
5 : 7	b : b	b : b	b : b	b : 1	2 : 4	5 : 7
8 : 10	b : b	b : b	b : 1	2 : 4	5 : 7	8 : 10
11 : 13	b : b	b : 1	2 : 4	5 : 7	8 : 10	11 : 13
14 : 16	b : 1	2 : 4	5 : 7	8 : 10	11 : 13	14 : 16
17 : 1920	2 : 1905	5 : 1908	8 : 1911	11 : 1914	14 : 1917	17 : 1920
1921 : 1923	1906 : 1908	1909 : 1911	1912 : 1914	1915 : 1917	1918 : 1920	b : b
1924 : 1926	1909 : 1911	1912 : 1914	1915 : 1917	1918 : 1920	b : b	b : b
1927 : 1929	1912 : 1914	1915 : 1917	1918 : 1920	b : b	b : b	b : b
1930 : 1932	1915 : 1917	1918 : 1920	b : b	b : b	b : b	b : b
1933 : 1935	1918 : 1920	b : b	b : b	b : b	b : b	b : b

It will be understood that an unlimited number of blue beam power combinations could be employed to produce the desired blue color at the corresponding dot location.

In FIGs. 41A-41F and 42A-42F, the spots of the spot pattern formed by the emitting ends 56 of the fibers 42 in one horizontal row of the output head 58 are identified as follows: the red spot in each row is represented by "×"; the green spot in each row is represented by "+"; and the four blue spots corresponding to the blue-w, blue-x, blue-y and blue-z laser beams are represented by "○", "⦶", "Ϙ", and "◉", respectively.

As shown in FIG. 41A-41F, when the polygon mirror facet 74 is in the desired position at a time s1 of the first scan by the bottom row of spots (RowD) of the pattern of spots the first dot location of the fourth line of the frame is written by the red × beam modulated for the value of the red color assigned to that pixel location in the video data, and the green and four blue beams, which if activated would write pixels to the left of the frame (shown with outlined symbols) are blanked by their respective modulators. Table EX-9 describes in tabular form the repositioning of the separate spots of the bottom row of spots at successive dot locations of the fourth line of the frame, as graphically shown in FIGs. 41A-41F and 42A-42F. It should be apparent from the illustration of FIGs. 40, 40S, 41A-41F and 42A-42F that with this method according to our invention, a beam of each red and green color modulated for the value of that pixel in the video data, and four separate beams of the blue color modulated for one quarter of the value of the same pixel in the video data, is projected for every dot in that line.

Referring to FIGs. 42A-42F which diagram the end of the scan pass at the end of the line as described in the lower portion of Table EX-9, beginning at time 1920, the red ×, green +, blue-w ○, blue-x ⦶, blue-y Ϙ and blue-z ◉ beams will write dots 1920, 1917, 1914, 1911, 1908 and 1905, respectively. After the blue-z ◉ beam writes dot 1920 at time t1935, all of the beams are blanked until the next facet of the polygon mirror is in position to begin the next horizontal scan, and the galvanometer mirror has adjusted vertically downward the desired number of lines on the screen to begin the next line.

EXAMPLES 10-11

Examples 10 and 11, shown in FIGs. 43 and FIGs. 44S, 45A-45F and 46A-46F, illustrate the pattern of spots shown in FIG. 5S projected by the output head configuration shown in FIG. 5, except that the red, green and blue beams are purposefully assigned to particular fibers and corresponding emitting ends to project spots of each color at particular positions in each row for the reasons described below.

EXAMPLE 10

In actual practice, it is possible that small vertical variations, within acceptable tolerances, will result when the emitting ends of the fibers are mounted in the output head, such that individual fibers may not be positioned exactly in a line of a row, i.e., spaced more or less closely to other rows. Further, we have determined that when the beam emitted from a fiber end is projected on the screen with the simple achromat lens we prefer, the size of the spot for each color may be different, such as the spot sizes shown in FIG. 43. In our preferred prototype embodiment at our preferred throw distance, the size of the red spot is roughly 4 mm in diameter, the size of the green spot is roughly 3.25 mm in diameter, and the size of the blue spot is roughly 2.6 mm in diameter. Because we believe the eye is most sensitive to the resolution of the spots in the green wavelengths, and because we prefer to employ as equal a spacing of the respective rows of the spot pattern as feasible, we prefer to select those fibers for transmitting the green wavelength beam having emitting ends in each row, and corresponding spots, that have the most even vertical spacing feasible. We further prefer to assign the red and blue wavelength beams to be transmitted by the remaining fibers in a particular row having emitting ends positioned so that the areas of each colored spot in a row of the spot pattern are most coincident, or correspond to the greatest extent, with the green spot in that row at each dot location on the screen when scanned, despite the slight misalignment of the emitting ends in a row, such as the arrangement shown in FIG. 43.

EXAMPLE 11

If manufacture of the output head can result in vertical alignment errors of emitting ends within rows, it follows that horizontal spacing errors or nonuniform spacing of emitting ends, and resulting spots, within a row may also occur that are possibly unique for each output head. Such nonuniform spacing is illustrated by the spot pattern shown in FIG. 44, wherein the spots are respectively spaced substantially different distances apart. We prefer to account for this nonuniform spacing by delaying the timing of the modulation of the beam to be emitted from that emitting end such that the spot illuminates the desired dot location on the screen, as shown in FIGs. 45A-45F and 46A-46F, and described in Tables EX-11A and EX-11B. Because the horizontal error is the same for all scan passes and horizontal repositioning of the spot pattern, the necessary delay may be incorporated for each output head at the factory when calibrating the particular laser projection system concerned. One should also consider that it is not necessary to use the same size fiber for each color, as assumed in previous examples herein. In our preferred fiber configuration, some fiber cores (but typically not the outer diameter of the cladding) are larger in diameter, thus being multimode, and others are smaller, closer, or more similar, to single mode. As noted above, most of the perception of resolution occurs in the green. Given potential losses in the process of inserting light into fibers 42, it may be advantageous to use single (or nearly single mode) fiber for the green beams, albeit at some lesser insertion efficiency where the higher insertion losses are made up by having more powerful laser beams, and more multimode fibers having lower insertion losses to more efficiently relay the red and blue laser beams, to attain the greatest feasible resolution of the photoptically perceived green spots while maintaining necessary overall brightness.

TABLE EX-11A

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figures: FIGs. 44-45 Vertical Adjustment: 4 lines
Pattern of Spots: Log Effective Row Spacing(all rows): 3 lines
Scan Pass: 3 Blank=b Spot Spacing within Row: 8,4 dots

	RowA			RowB			RowC			RowD		
	Blue	Red	Grn	Red	Grn	Blue	Grn	Blue	Red	Red	Grn	Blue
Line	time t1						Dot Locations					
3	b	b	b									
6				b	b	1						
9							b	b	b			
12										b	b	1
Line	time t3						Dot Locations					
3	b	b	1									
6				b	b	3						
9							b	b	1			
12										b	b	3
Line	time t5						Dot Locations					
3	b	b	3									
6				b	b	5						
9							b	b	3			
12										b	1	5
Line	time t9						Dot Locations					
3	b	3	7									
6				b	1	9						
9							b	b	7			
12										b	5	9
Line	time t15						Dot Locations					
3	1	9	13									
6				3	7	15						
9							1	5	13			
12										3	11	15

TABLE EX-11B

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figures: FIGs. 44-46 Vertical Adjustment: 4 lines
Pattern of Spots: Log Effective Row Spacing(all rows): 3 lines
Scan Pass: 3 Blank=b Spot Spacing within Row: 8,4 dots

	RowA			RowB			RowC			RowD		
	Blue	Red	Grn	Red	Grn	Blue	Grn	Blue	Red	Red	Grn	Blue
Line	time t1920						Dot Locations					
3	1906	1914	1918									
6				1908	1912	1920						
9							1906	1910	1918			
12										1908	1916	1920
Line	time t1922						Dot Locations					
3	1908	1916	1920									
6				1910	1914	b						
9							1908	1912	1920			
12										1910	1918	b
Line	time t1926						Dot Locations					
3	1912	1920	b									
6				1914	1918	b						
9							1912	1916	b			
12										1914	b	b
Line	time t1930						Dot Locations					
3	1916	b	b									
6				1918	b	b						
9							1916	1920	b			
12										1918	b	b
Line	time t1934						Dot Locations					
3	1920	b	b									
6				b	b	b						
9							1920	b	b			
12										b	b	b

EXAMPLE 12

Example 12, shown in FIGs. 47, 47S, 48 and 49, and described in Tables 12A and EX-12B, illustrates an alternate output head configuration from that shown in FIG. 5 and in the other examples, wherein the rows of three emitting ends which are oriented substantially in vertical alignment in the prior

embodiments of output heads are instead positioned out of vertical alignment, in a substantially stepped arrangement to produce the pattern of spots on the screen shown in FIG. 47S. The output head includes four groups of three emitting ends, with each group arranged in horizontal alignment. In this arrangement of the output head emitting ends, and therefore the pattern of spots, the three primary colors are assigned to each group or row. The reordering of the video pixel data for this Example 12 is graphically shown in FIGs. 48A-48E and 49A-49E, and described on a line and spot basis in Tables EX-12A and EX-12B. In this embodiment, the adjacent rows preferably have an effective row spacing of 1 line, that is the lines written during each scan pass are vertically adjacent. Although not required, during a complete initial scan pass lines L1-L4 of the frame are preferably respectively written with rows RowA, RowB, RowC and RowD of the pattern of spots. Because of the orientation of the pattern of spots shown in FIG. 47S and the assumed left to right scanning of the spot pattern, the spots of RowD will each illuminate the dot locations of line 1 of the frame in right to left sequence at different times, followed by RowC, RowB and RowA. Tables EX-12A and EX-12B and FIGs. 48A-48E and 49A-49E describe the writing of the lines and dot locations of the lines for the pattern of spots of this Example 12. In the embodiment of this Example 12, it is not necessary to blank any rows at the top or bottom of the frame, as the effective line spacing is one. Reordering, or time combination, of the video pixel data, and blanking of the spots to the left and right of the frame at the beginning and end of each scan pass is still required, however, to an even greater extent than shown in FIG. 13 above, because the width of the spot pattern is greater. For this Example 12, the horizontal spacing between spots emitted from adjacent fiber emitting ends is assumed to be three dots on the screen, i.e., there are two dots between horizontally adjacent spots on the screen. We also assume an effective horizontal spot spacing between the ends of horizontally adjacent rows of three dots. We further assume a red, green, blue order of each row of emitting

ends. It should be understood that these assumptions are merely for illustrative purposes, and that larger or smaller effective horizontal spot spacings and/or vertical row spacing may be required in actual practice, and that more or fewer emitting ends per row, and more or fewer rows of emitting ends, may be employed within the concept of our invention.

Thus, as shown in FIGs. 48A-48E and 49A-49E and Tables EX-12A and EX-12B, for a horizontal scan at scan pass time s1 scanning lines L1, L2, L3 and L4, at time t1 dot 1 of line L1 is written by the red spot of RowA, while the green and blue spots of RowA and all spots of RowB, RowC and RowD are blanked. The remaining illuminations of the dot locations of lines L1-L4 at various times during scan pass s1 are described in Tables EX-12A and EX-12B.

The detailed description relating to FIGs. 48A-48E, and to Table EX-12A, illustrates the time combination required for the spot pattern shown in FIG. 47S at the beginning of the scan pass. As shown in FIGs. 49A-49F and described in Table EX-12B, with similar writing of spots on dot locations at the end of the scan pass for lines L4, L3, L2 and L1, and blanking of spots in each RowD, RowC, RowB and RowA in the inverse order of that needed at the beginning of the scan pass, 1953 horizontal dot shifts of the spot pattern will be needed to complete the lines of the first horizontal scan pass. When the complete frame of 1080 lines is written, the galvanometer mirror retraces to the top of the frame, and the scanning of a new frame is begun. Of course, the number of configurations of this type of output head and resulting spot pattern are almost endless. The primary limitation of an output head having the type of spot pattern illustrated by this Example 12 is the overall width of the spot pattern. However, this configuration has the advantage of reducing the horizontal scan passes per frame, and somewhat simplifying the timing of the input pixel data.

TABLE EX-12A

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figures: FIGs. 47-49 Vertical Adjustment: 4 lines
Pattern of Spots: Step Effective Row Spacing(all rows): 1 line
Scan Pass:1 Blank=b Spots betw Rows:3 Spots Spacing w/I Row: 3

	RowD			RowC			RowB			RowA		
	Red	Grn	Blue	Red	Grn	Blue	Red	Grn	Blue	Red	Grn	Blue
Line	time t1				Dot Locations							
1	1	b	b									
2				b	b	b						
3							b	b	b			
4										b	b	b
Line	time t7				Dot Locations							
1	7	4	1									
2				b	b	b						
3							b	b	b			
4										b	b	b
Line	time t10				Dot Locations							
1	10	7	4									
2				1	b	b						
3							b	b	b			
4										b	b	b
Line	time t19				Dot Locations							
1	19	16	13									
2				10	7	4						
3							1	b	b			
4										b	b	b
Line	time t28				Dot Locations							
1	28	25	22									
2				19	16	13						
3							10	7	4			
4										1	b	b
Line	time t34				Dot Locations							
1	34	31	28									
2				25	22	19						
3							16	13	10			
4										7	4	1

TABLE EX-12B

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3
Corresponding Figures: FIGs.47-49 Vertical Adjustment: 4 lines
Pattern of Spots: Step Effective Row Spacing(all rows): 1 line
ScanPass:1 Blank=b Spots between Rows:3 Spots spacing w/I Row:3

	RowD			RowC			RowB			RowA		
	Red	Grn	Blue	Red	Grn	Blue	Red	Grn	Blue	Red	Grn	Blue
Line time t1920						Dot Locations						
1	1920	1917	1914									
2				1911	1908	1905						
3							1902	1899	1896			
4										1893	1890	1887
Line time t1921						Dot Locations						
1	b	1918	1915									
2				1912	1909	1906						
3							1903	1900	1897			
4										1894	1891	1888
Line time t1929						Dot Locations						
1	b	b	b									
2				1920	1917	1914						
3							1911	1908	1905			
4										1902	1899	1896
Line time t1935						Dot Locations						
1	b	b	b									
2				b	b	1920						
3							1917	1914	1911			
4										1908	1905	1902
Line time t1944						Dot Locations						
1	b	b	b									
2				b	b	b						
3							b	b	1920			
4										1917	1904	1911
Line time t1953						Dot Locations						
1	b	b	b									
2				b	b	b						
3							b	b	b			
4										b	b	1920

EXAMPLES 13-14

FIGs. 50, 50S, and 51, and FIGs. 52, 52S and 53, and corresponding Tables EX-13 and EX-14, respectively illustrate for Examples 13 and 14 alternate versions of the stepped array and pattern of spots described in FIGs. 47 and 47S for Example 12, wherein the linear array of emitting ends and the pattern of spots (FIGs. 50S and 52S respectively)projected by the arrays shown in FIGs. 50 and 52 are slanted somewhat with respect to the horizontal aspect of the frame projected on the screen to somewhat approximate the result of the stepped configuration of Example 12, but in a significantly more manufacturable flat or linear alignment. For Examples 13 and 14 the groups of emitting ends and corresponding spots of the spot pattern are arranged in groups of red, green and blue spots, herein referred to as "RGB groups A, B, C and D", respectively. The RGB groups of spots shown in FIGs. 50S and 52S are not horizontally aligned as shown in FIG. 47S, but the spots produced thereby do significantly, both physically and perceptually, overlap vertically as shown in FIGs. 51 and 52. Each such RGB group corresponds to a row of Example 12 above, having substantially the same line reordering and time combination within rows shown in FIGs. 48 and 49 of Example 12.

EXAMPLE 13

Since the outboard red and blue spots of each RGB group are not horizontally aligned with the center green spots of their own RGB group, the edges of the color spots of one group may overlap one or more color spots of an adjacent group somewhat, as shown in FIG. 51. This overlap is not typically perceived since most of the resolution perception of an image occurs in the green, and even though the red and blue are not exactly coincident with the green spot of the respective RGB group, resolution doesn't noticeably suffer.

By selecting different orders for the colors of the fibers within particular RGB groups such as red-green-blue for one RGB group and green-blue-red for another RGB group, the perceived

vertical position of the spots of each RGB group projected on the screen by the linear array will be effectively vertically spaced a line apart. It may be preferable to place green, the more photoptically perceived color, at the center of each RGB group. In other words, if the four green spots are at the middle of each RGB group, an appropriate slant or angle of the head will write four lines of green spots with an effective row spacing of one line (or more) on the screen, as shown for Example 12 and FIG. 48 and Tables EX-12A and EX-12B. As previously noted, the pattern of those spots and the extent of overlap is graphically shown in FIG. 51. Although it might seem that the omission of the discrete steps of the emitting end array and resulting spot pattern of Example 13 might not yield the effect shown in FIGs. 48 and 49 of Example 12, appropriate assignment of the colors to the appropriate emitting ends as described for this Example 13 should yield the appropriate composite spots at effective dot locations of each line on the screen that are perceptually equivalent to the dot locations illustrated in Example 12.

EXAMPLE 14

FIGs. 52 and 52S illustrate an alternate embodiment of the slanted configuration shown in FIGs 50 and 50S, respectively, wherein the fibers, and therefore the spots of the spot pattern, are spaced closer together to minimize the effective spacing of spots within an RGB group and thereby reduce the portion of the red and blue spots that do not overlap the more photoptically perceived green spot. Referring again to FIG. 52, the cladding of the fibers are shaved, skived or ground away to reduce the thickness of the cladding, or the distance between fiber centers, and therefore the effective horizontal spot spacing within each RGB group. This fiber treatment may also be useful in array configurations other than those illustrated in Examples 13 and 14, both for the spacing of beams within horizontal rows and effective vertical spacing between rows, because the greater the spacing, the greater the overlap of rows of beams that must be blanked at the top and bottom of the frame.

The output head configuration illustrated in FIG. 52 and the resulting spot pattern shown in FIG. 52S may enable the adjustment of the system to provide different effective row spacing, resolutions, and aspect ratios by altering the slant or angle of the rows with respect to the horizontal axis of the screen. It may be seen that as the angle of any of the rows of emitting ends, and consequently of the spot pattern, from horizontal is varied, the effective vertical row spacing on the screen is varied. The angle of the output array, or pattern of spots, may be manually adjustable, such as when calibrating the system at the factory, or at a particular location. Automatic, or dynamic, adjustment could also be accomplished during setup of the laser projection system at a new location, or as part of a portable system used at different locations, or to accommodate different aspect ratio and resolution requirements for the video image or for different video sources.

EXAMPLES 15-16

For Examples 15 and 16, FIGs. 54 and 58 show alternate output head emitting head configurations and FIGs. 54S and 58 show the corresponding alternate spot patterns, similar to that of the linear array of Example 13 shown in FIGs. 50 and 50S, but angled more from horizontal so that each spot of the spot pattern projected on the screen is at an effective row spacing of 1 line. The difference between Examples 15 and 16 resides in the assignment of colors of beams to the fibers. Example 15 employs red-green-blue groups, whereas Example 16 employs groups of colors, for example, red-red-red-red/green-green-green-green/blue-blue-blue-blue.

EXAMPLE 15

For this Example 15, a 12 emitting end output head array projecting a 12 spot pattern, we assume that red, green, blue beams are assigned to fibers in groups of three (as shown in FIGs. 54, 54S, and 55-57), a 4 line vertical adjustment equal to the number of groups of RGB emitting ends, and identify each of the twelve spots, from top to bottom of the spot pattern, as Ra,

Ga, Ba, Rb, Gb, Bb, Rc, Gc, Bc, Rd, Gd and Bd, respectively. As shown in FIGs. 55A-55H and Table EX-15A all lines of a frame will be scanned with spots of all three primary colors in 272 scan passes and lines L1-L4 of a frame will be scanned with spots of all three primary colors after initial scan passes s1, s2 and s3. FIGs. 56A-56C and 57A-57C show, and Tables EX-15A, EX-15B and EX-15C describe, the time delays necessary to scan each dot location in a line for scan pass s3, revealing the necessity of 1953 horizontal adjustments of the spots to complete each scan pass,

TABLE EX-15A

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Figure: FIGs. 54-58 Vertical Adjustment: 4 lines
Blank = b Effective Vertical Spacing: 1 lines

	Lines Written by Respective Spots											
Scan Pass	Ra	Ga	Ba	Rb	Gb	Bb	Rc	Gc	Bc	Rd	Gd	Bd
1	b	b	b	b	b	b	b	b	1	2	3	4
2	b	b	b	b	1	2	3	4	5	6	7	8
3	1	2	3	4	5	6	7	8	9	10	11	12
4	5	6	7	8	9	10	11	12	13	14	15	16
:	:	:	:	:	:	:	:	:	:	:	:	:
269	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276
270	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280
271	1273	1274	1275	1276	1277	1278	1279	1280	b	b	b	b
272	1277	1278	1279	1280	b	b	b	b	b	b	b	b

or an overscan at one side of the frame of 33 dot locations.

EXAMPLE 16

For Example 16, FIG. 58 shows an alternate output head configuration, identical to that of the linear array of Example 15 shown in FIG. 54, but having a different assignment of colors to produce a substantive alternative to Example 15. As with Example 15, each spot of the spot pattern projected on the screen shown in FIG. 58S for this Example 16 has an effective row spacing of 1 line. For this Example 16, however, we assume that red, green, and blue beams are assigned to fibers in three groups of four fibers, the fibers of each group all having the same

color (as shown in FIGs. 58, 58S and 59-61), although we assume a 4 line vertical adjustment equal to the number of groups of RGB emitting ends as in Example 5.

TABLE EX-15B

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Figures: FIGs. 54,56 Vertical Adjustment: 4 lines
Pattern of Spots: Ramp Effective Vertical Spot Spacing:1 line
Scan Pass:3 Blank=b Effective Horizontal Spot Spacing: 3

	Ra	Ga	Ba	Rb	Gb	Bb	Rc	Gc	Bc	Rd	Gd	Bd
Line	time t1				Dot Locations							
1	1											
2		b										
3			b									
4				b								
5					b							
6						b						
7							b					
8								b				
9									b			
10										b		
11											b	
12												b
Line	time t16				Dot Locations							
1	16											
2		13										
3			10									
4				7								
5					4							
6						1						
7							b					
8								b				
9									b			
10										b		
11											b	
12												b
Line	time t34				Dot Locations							
1	34											
2		31										
3			28									
4				25								
5					22							
6						19						
7							16					
8								13				
9									10			
10										7		
11											4	
12												1

TABLE EX-15C

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Figures: FIGs. 55,58 Vertical Adjustment: 4 lines
Pattern of Spots: Ramp Effective Vertical Spot Spacing:1 line
Scan Pass:3 Blank=b Effective Horizontal Spot Spacing: 3

	Ra	Ga	Ba	Rb	Gb	Bb	Rc	Gc	Bc	Rd	Gd	Bd
Line	**time t1920**						**Dot Locations**					
1	1920											
2		1917										
3			1914									
4				1911								
5					1908							
6						1905						
7							1902					
8								1899				
9									1896			
10										1893		
11											1890	
12												1887
Line	**time t1938**						**Dot Locations**					
1	b											
2		b										
3			b									
4				b								
5					b							
6						b						
7							1920					
8								1917				
9									1914			
10										1911		
11											1908	
12												1905
Line	**time t1953**						**Dot Locations**					
1	b											
2		b										
3			b									
4				b								
5					b							
6						b						
7							b					
8								b				
9									b			
10										b		
11											b	
12												1920

TABLE EX-16A

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Figure: FIGs. 58-61 Vertical Adjustment: 4 lines
Blank = b Effective Vertical Spacing: 1 lines

Scan Pass	Lines Written by Respective Spots											
	Ra	Rb	Rc	Rd	Ga	Gb	Gc	Gd	Ba	Bb	Bc	Bd
1	b	b	b	b	b	b	b	b	1	2	3	4
2	b	b	b	b	1	2	3	4	5	6	7	8
3	1	2	3	4	5	6	7	8	9	10	11	12
4	5	6	7	8	9	10	11	12	13	14	15	16
:	:	:	:	:	:	:	:	:	:	:	:	:
269	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276
270	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280
271	1273	1274	1275	1276	1277	1278	1279	1280	b	b	b	b
272	1277	1278	1279	1280	b	b	b	b	b	b	b	b

In FIG. 59 we identify the twelve spots, from top to bottom of the spot pattern, as Ra, Rb, Rc, Rd, Ga, Gb, Gc, Gd, Ba, Bb, Bc and Bd, respectively. As shown in FIG. 59 and Table EX-16A, all lines of a frame will be scanned with spots of all three primary colors in 272 scan passes and lines L1-L4 of a frame will be scanned with spots of all three primary colors after initial scan passes s1, s2 and s3. FIGs. 60A-60J and 61A-61J show, and Tables EX-16B and EX-16C describe, the time delays or time combining necessary to scan each dot location in a line for scan pass s3, revealing the necessity of 1953 horizontal adjustments of the spots to complete each scan, or an overscan at one side of the frame of 33 dot locations.

The primary differences between Examples 15 and 16 and previous examples is that the line reordering for the video pixel data is substantially less complicated than for the preceding examples where all three primary colors are written in substantially the same line. For Examples 15 and 16, the pixel data need not be reordered in the same way as in preceding examples, and may simply be delayed for the necessary time until the line is written.

TABLE EX-16B

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Figures: FIGs. 58-61 Vertical Adjustment: 4 lines
Pattern of Spots:Ramp Effective Vertical Spot Spacing:1 line
Scan Pass:3 Blank=b Effective Horizontal Spot Spacing:3 dots

	Ra	Rb	Rc	Rd	Ga	Gb	Gc	Gd	Ba	Bb	Bc	Bd
Line	time t1						Dot Locations					
1	1											
2		b										
3			b									
4				b								
5					b							
6						b						
7							b					
8								b				
9									b			
10										b		
11											b	
12												b
Line	time t16						Dot Locations					
1	16											
2		13										
3			10									
4				7								
5					4							
6						1						
7							b					
8								b				
9									b			
10										b		
11											b	
12												b
Line	time t34						Dot Locations					
1	34											
2		31										
3			28									
4				25								
5					22							
6						19						
7							16					
8								13				
9									10			
10										7		
11											4	
12												1

TABLE EX-16C

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Figures: FIGs. 58-61 Vertical Adjustment: 4 lines
Pattern of Spots:Ramp Effective Vertical Spot Spacing:1 line
Scan Pass:3 Blank=b Effective Horizontal Spot Spacing:3 dots

	Ra	Rb	Rc	Rd	Ga	Gb	Gc	Gd	Ba	Bb	Bc	Bd
Line	time t1920					Dot Locations						
1	1920											
2		1917										
3			1914									
4				1911								
5					1908							
6						1905						
7							1902					
8								1899				
9									1896			
10										1893		
11											1890	
12												1887
Line	time t1938					Dot Locations						
1	b											
2		b										
3			b									
4				b								
5					b							
6						b						
7							1920					
8								1917				
9									1914			
10										1911		
11											1908	
12												1905
Line	time t1953					Dot Locations						
1	b											
2		b										
3			b									
4				b								
5					b							
6						b						
7							b					
8								b				
9									b			
10										b		
11											b	
12												1920

In Examples 15 and 16, instead of placing the pixel data in the buffer in the reordered position corresponding to the line position so that each line can be written at a particular time out of order from the order in the video pixel data, a simple delay can be employed because the order in which the lines are written is not out of order, but only time shifted. The time combining delay within a line of dot locations is similar to that of prior examples, except it is combined with a delay of a number of scan passes, in Examples 15 and 16, one or two scan passes.

For the following further illustration of the differences between the reordering of Examples 15 and 16 and the prior examples, we assume the same configuration of Examples 15 and 16 and the configuration of the preferred embodiment, namely a 4 row by 3 emitting end per row output head and an effective row spacing of 5 lines. Thus, in a frame defined by the pixel data, at time 1 of scan pass s1, pixel location 1 in line 1 is scheduled to be written with red, green and blue values. In order to write dot location D1 in line L1 with the assumed 4x3 configuration, other lines of the frame must be written in the following order: lines L4, L8 & L3, L12 & L7 & L2, and then line L1 along with lines L16 & L11 & L6. With Examples 15 and 16, to write dot location D1 in line L1, red is written at the same time called for in the pixel data, at time t1 of scan pass s1, green is written at time t10 of scan pass s5, or delayed 4 lines (one scan pass) and 9 dot shifts; and blue is written at time t19 of scan pass s9, or delayed 8 lines and 18 dot shifts.

While the pattern of spots projected on the screen by the linear array, whether it be that shown in Examples 23 and 24, or that shown in Examples 15 and 16, is aligned in a straight angled line with respect to horizontal, this array is in actuality a two-dimensional pattern of spots with respect to the sweep or scan or line direction during the scan pass.

As noted previously, all of the foregoing examples are only intended to demonstrate the breadth of our invention. Many additional variations on emitting head configuration, pattern of spots, and effective row spacing are possible, including

configurations that blend some of the features and principles noted previously. One such example would be a "totem pole" configuration as shown in Figures 62 and 62S which alternates rows of single emitting ends with rows of two emitting ends in a "log-like" pattern. Preferably, the green beams are assigned to the rows having a single fiber because the fiber may be smaller single mode fiber, with benefits previously discussed.

EXAMPLES 17-19

All of the preceding examples have assumed that the image is progressively scanned, that is, all of the lines are written in each vertical frame pass. Although progressive scanning is the preferred mode for our laser projector, interlaced scanning is also facilitated by our invention as shown in the following three Examples 17-19.

These Examples 17-19 are based on the preferred laser projection system of FIGs. 1 and 2, and use substantially the same output head configurations and corresponding spot patterns of the previous progressive scanning Examples. The interlaced scanning Examples 17-19 employ reordering of the input pixel data similar to that for the progressive scanning examples, but use different adjustments of the galvanometer mirror. While the prior examples assume the preferred standard HDTV resolution of 1920x1080p at a refresh rate of 60 frames per second or better, the following Examples 17-19 assume an alternate HDTV resolution of 1920x1080i, where 60 subframes are written per second, producing 30 interlaced complete frames per second. Although our examples illustrate interlacing using two subframes, it should be understood that more than two subframes could be employed. One possible interlacing approach would be to employ three subframes, with two sweep or scan paths of other subframes between lines written during each sweep or scan pass of a subframe.

The following examples illustrate three different ways of accomplishing interlacing with our invention.

EXAMPLE 17

For this Example 17, we assume a 12 emitting end array projecting a 12 spot pattern in a ramp configuration projecting

a pattern of spots such as shown in Example 15 and in FIGs. 54 and 54S. We further assume an effective row spacing of 2 lines, as opposed to the 1 line effective row spacing of Example 15. The effective row spacing on the screen can be easily changed by doubling the angle of the ramp from horizontal, shown in FIG. 54 to produce a pattern of spots with a vertical effective row spacing of two lines. Moreover, instead of the four line vertical adjustment of Example 15, we assume an eight line vertical adjustment between the initiation of each sweep or line scan during the scanning of each subframe. One way of accomplishing this is by slowing the mirror polygon to half the rate described for Example 15.

We further assume that the galvanometer is positioned at the beginning of the first of the pair of subframes ("Subframe A") to begin writing of the subframe so that the odd-numbered lines, i.e., 1, 3, 5, 7, 9, ..., 1075, 1077, and 1079 are written, and the galvanometer is positioned at the beginning of the second of the pair of subframes ("Subframe B") to begin writing of the subframe so that the even-numbered lines, i.e., 2, 4, 6, 8, 10, ..., 1076, 1078, and 1080 are written.

Referring to FIGs. 63A-63H and Table EX-17A, the reordering of the data for Subframe A is illustrated. It should be noted that the number of scan passes to write the first subframe is half that required to write a complete frame in progressive scanning of Example 15, namely 136 for interlaced versus 272 for progressive. Instead of beginning with writing line 4 of the frame as in the progressive scanning Example 15, Subframe A begins with writing line 7 of the frame, which is effectively the fourth line of Subframe A at an effective row spacing for the subframe of 1 subframe line. The effective subframe row spacing of 1 subframe line works for the same basic reasons as outlined for the 1 regular frame line effective row spacing illustrated in FIGs. 55A-55J for Example 15. The reordering of the data for Subframe B is illustrated in FIGs. 64A-64H and Table EX-17B. It should be noted that each subframe writes 540 lines of the 1080 lines of a complete frame, and that the two subframes interlaced

will write the same number of scan passes as one frame of progressive scanning.

TABLE EX-17A

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Fig: FIGs. 54,63 Vertical Adjustment: 8 lines
Subframe: A Blank = b Effective Vertical Spacing: 2 lines

Scan Pass	Lines Written by Respective Spots											
	Ra	Ga	Ba	Rb	Gb	Bb	Rc	Gc	Bc	Rd	Gd	Bd
1	b	b	b	b	b	b	b	b	1	3	5	7
2	b	b	b	b	1	3	5	7	9	11	13	15
3	1	3	5	7	9	11	13	15	17	19	21	23
4	9	11	13	15	17	19	21	23	25	27	29	31
:	:	:	:	:	:	:	:	:	:	:	:	:
134	1049	1051	1053	1055	1057	1059	1061	1063	1065	1067	1069	1071
135	1057	1059	1061	1063	1065	1067	1069	1071	1073	1075	1077	1079
136	1065	1067	1069	1071	1073	1075	1077	1079	b	b	b	b
137	1073	1075	1077	1079	b	b	b	b	b	b	b	b

Given an interlaced source signal, this approach is uncomplicated, because the source material for a given subframe is completely written in one vertical sweep, and the only compensations for interlacing are changing the speed of the polygon and an alternating initial position of the galvanometer for the subframes.

EXAMPLE 18

In Example 18, our next preferred example, we show interlacing where the re-ordering for the subframes is handled differently. In this example, the head configuration is "bricks" as in FIGs. 5 and 5S or "logs" as in FIGs. 27 and 27S. Herein the subframes are not divided by odd-even lines, but divided by odd-even scan pass number. Referring to the prior progressive scanning Examples 1 and 4, at the beginning of the first horizontal pass in the first Subframe A, the galvanometer starts in a position to write those lines exactly as in the first

TABLE EX-17B

Output Head Configuration (spot pattern)- Rows: 12 Spots/Row: 1
Corresponding Fig: FIGs. 63,64 Vertical Adjustment: 8 lines
Subframe: B Blank = b Effective Vertical Spacing: 2 lines

Scan Pass	Lines Written by Respective Spots											
	Ra	Ga	Ba	Rb	Gb	Bb	Rc	Gc	Bc	Rd	Gd	Bd
1	b	b	b	b	b	b	b	b	2	4	6	8
2	b	b	b	b	2	4	6	8	10	12	14	16
3	2	4	6	8	10	12	14	16	18	20	22	24
4	10	12	14	16	18	20	22	24	26	28	30	32
:	:	:	:	:	:	:	:	:	:	:	:	:
134	1050	1052	1054	1056	1058	1060	1062	1064	1066	1068	1070	1072
135	1058	1060	1062	1064	1066	1068	1070	1072	1074	1076	1078	1080
136	1066	1068	1070	1072	1074	1076	1078	1080	b	b	b	b
137	1074	1076	1078	1080	b	b	b	b	b	b	b	b

pass in such prior Examples. For the next pass, the galvanometer has moved down 8 full frame lines, rather than 4 lines of the prior Examples, and on the next pass writes those lines written by the third pass in the prior Examples. Thus all the lines appropriate to the odd numbered passes are successively written, as shown in Table 18A and FIGs. 65A-65H for the first Subframe A of the frame being written.

For the first pass of the next Subframe B, the galvanometer is positioned 4 full frame lines lower at the beginning of the first scan pass than the initial scan pass of Subframe A. This first scan pass of Subframe B corresponds to the second scan pass of the progressively scanned frame. At the beginning of the next scan pass of Subframe B, the galvanometer has been adjusted down eight lines from the beginning of the first scan pass, and so forth.

TABLE EX-18A

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3 Corresponding Figure: FIG. 65 Vertical Adjustment: 8 lines Subframe: A Effective Row Spacing(all rows): 9 lines				
	Lines Written by Respective Rows of Emitting Ends			
Scan Pass	RowA	RowB	RowC	RowD
1	b	b	b	4
2	b	b	3	12
3	b	2	11	20
4	1	10	19	28
5	9	18	27	36
⋮	⋮	⋮	⋮	⋮
134	1041	1050	1059	1068
135	1049	1058	1067	1076
136	1057	1066	1075	b
137	1065	1074	b	b
138	1073	b	b	b

For each subframe, the process ends when half the number of passes is made when compared with the referenced non-interlaced examples. For this interlacing process, however, the reordering of the data is more complex, particularly if a standard interlaced input signal is employed.

TABLE 18B

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 3 Corresponding Figure: FIG. 66 Vertical Adjustment: 8 lines Subframe: B Effective Row Spacing(all rows): 9 lines				
	Lines Written by Respective Rows of Emitting Ends			
Scan Pass	RowA	RowB	RowC	RowD
1	b	b	b	8
2	b	b	7	16
3	b	6	15	24
4	5	14	23	32
5	13	22	31	40
⋮	⋮	⋮	⋮	⋮
134	1045	1054	1063	1072
135	1053	1062	1071	1080
136	1061	1070	1079	b
137	1069	1078	b	b
138	1077	b	b	b

EXAMPLE 19

For this Example 19, we assume a 12 emitting end output head and a 12 spot pattern in a four row by three emitting ends per row array, with red, green and blue beams assigned to the three fibers in each row, such as shown in FIGs. 5 and 5S and in FIGs.27 and 27S. Unlike Example 18, however, this type of interlacing employs an adjustment of the effective row spacing similar to that of Example 17, wherein the effective row spacing is substantially doubled, and odd and even lines written during successive subframes. Unlike Example 17, the effective row spacing of the brick or log pattern output head configuration of this Example 19 cannot be as easily adjusted as with the ramp configuration of Example 17. Further, an effective row spacing of 10 lines is required, as opposed to the 5 lines effective row spacing of the introductory example. As with Examples 17 and 18, an eight full frame line vertical adjustment is assumed between the initiation of each sweep during the scanning of each subframe, to effectively write the odd-numbered lines, I. e., 1, 3, 5, 7, 9, ..., 1075, 1077, and 1079 during Subframe A, and the even-numbered lines, I. e., 2,4,6,8,10,..., 1076, 1078, and 1080 during Subframe B.

Referring to FIGs 67A-67H and Table EX-19A, the reordering of the input data at the beginning and end of Subframe A is illustrated. As with Example 18, the number of scan passes to write the first Subframe A is half that to write a complete frame in progressive scanning of Example 6, namely 138 for interlaced versus 276 for progressive. Instead of beginning with writing line 4 of the frame as in progressive scanning Example 6, Subframe A begins with writing line 7 of the frame, which is effectively line 4 of the subframe at an effective row spacing for the subframe of 5 subframe lines. Note that an effective row spacing of ten complete frame lines that is ineffective for progressive scanning is effective for interlaced scanning.

TABLE EX-19A

Output Head Configuration (spot pattern) - Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 67 Vertical Adjustment: 8 lines
Subframe: A Effective Row Spacing (all rows): 10 lines

Scan Pass	Lines Written by Respective Rows of Emitting Ends			
	RowA	RowB	RowC	RowD
1	b	b	b	7
2	b	b	5	15
3	b	3	13	23
4	1	11	21	31
5	9	19	29	39
⋮	⋮	⋮	⋮	⋮
135	1049	1059	1069	1079
136	1057	1067	1077	b
137	1065	1075	b	b
138	1073	b	b	b

The effective subframe row spacing of 5 subframe lines is effective for the same basic reasons as outlined for the five line effective row spacing.

The reordering of the data Subframe B is illustrated in FIGs 68A-68H and Table EX-19B. It should be noted that each subframe writes 540 lines of the 1080 lines of a complete frame and that the two subframes interlaced will write the same number of scan passes as one frame of progressive scanning.

To summarize these three examples, interlacing can be accomplished in a number of different ways, a wider variety than when only one line is being written per pass. Any of a number of interlacing processes may be selected within the present invention.

TABLE EX-19B

Output Head Configuration (spot pattern) – Rows: 4 Spots/Row: 3
Corresponding Figure: FIG. 68 Vertical Adjustment: 8 lines
Subframe: B Effective Row Spacing(all rows): 10 lines

	Lines Written by Respective Rows of Emitting Ends			
Scan Pass	RowA	RowB	RowC	RowD
1	b	b	b	8
2	b	b	6	16
3	b	4	14	24
4	2	12	22	32
5	12	20	30	40
:	:	:	:	:
135	1050	1060	1070	1080
136	1058	1068	1078	b
137	1066	1076	b	b
138	1074	b	b	b

EXAMPLE 20

FIG. 69 illustrates an extension of the ramp principle shown in Examples 15 and 16, wherein an array of 36 fibers is arranged in a configuration of three rows of ramp configuration emitting ends. The slant or angle of the rows is selected to achieve an effective spot spacing of 1 line between the spots in each row projected by the array. Moreover, the distance between each row is selected to provide an effective spacing of 1 line between the spots projected by the beams emitted from the emitting ends at the opposite ends of adjacent rows. For this Example 20, the colors of the laser beams assigned to each fiber within each row are arranged in RRRR-GGGG-BBBB groups as in Example 16. A variety of arrangements of emitting ends within rows can be employed, including an arrangement such as in Example 15, so long as each column of emitting ends within the fiber output head is assigned one each of red, green and blue laser beams.

The resultant line reordering necessary to progressively scan a 1920x1080p image on the screen is similar to that of Example 16 illustrated in FIGs. 59A-59H and Table EX-16. The

writing of successive dot locations within lines during each scan pass for each row of ramped emitting ends would be similar to that of Tables EX-16B and EX-16C, except for a slightly different line reordering and time combination. For clarity, Table EX-19B, EX-20C and EX-20D are included herein reflecting three different times at the beginning of scan pass 3. It is presumed that the end of the scan pass illustrated for Example 16 in Table EX-16C will be apparent from a comparison of Tables EX-16B and EX-20B through EX-20D.

The order of the assignment of colors within a row may not be the same as within any other row in order to write each dot location with all three colors, as shown in Table EX-20 and FIGs. 70A - 70H. It will be apparent after the teachings of the 4x3 brick and log, and the 12x1 ramp emitting end configurations above that the configuration of this Example 20 has aspects of each. A primary advantage of this configuration and resulting spot pattern on the screen is the ability to drastically reduce the speed or increase facet size of the polygon mirror or other horizontal scanning component because the number of scan passes has been cut by a factor of about three to 92 scan passes per progressively scanned frame.

This configuration also allows for much higher aggregate power levels to be conveyed to the screen, thus permitting this system to be used for still larger screen sizes. Further, maintaining the speed of the mirror polygon with this head configuration would allow the achievement of higher resolution levels within the restrictions of current technology and components.

TABLE EX-20A

Output Head Configuration (spot pattern)- Rows: 36 Spots/Row: 1
Corresponding Figure: FIGs. 69,70 Vertical Adjustment: 12 lines
Blank = b Effective Vertical Spacing: 1 lines

	Lines Written by Respective Spots											
Scan Pass	Gi Be Ra	Gj Bf Rb	Gk Bg Rc	Gl Bh Rd	Bi Re Ga	Bj Rf Gb	Bk Rg Gc	Bl Rh Gd	Ri Ge Ba	Rj Gf Bb	Rk Gg Bc	Rl Gh Bd
	b	b	b	b	b	b	b	b	b	b	b	b
1	b	b	b	b	b	b	b	b	b	b	b	b
	1	2	3	4	5	6	7	8	9	10	11	12
	b	b	b	b	b	b	b	b	b	b	b	b
2	1	2	3	4	5	6	7	8	9	10	11	12
	13	14	15	16	17	18	19	20	21	22	23	24
	1	2	3	4	5	6	7	8	9	10	11	12
3	13	14	15	16	17	18	19	20	21	22	23	24
	25	26	27	28	29	30	31	32	33	34	35	36
	13	14	15	16	17	18	19	20	21	22	23	24
4	25	26	27	28	29	30	31	32	33	34	35	36
	37	38	39	40	41	42	43	44	45	46	47	48
:	:	:	:	:	:	:	:	:	:	:	:	:
	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256
90	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268
	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280
	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268
91	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280
	b	b	b	b	b	b	b	b	b	b	b	b
	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280
92	b	b	b	b	b	b	b	b	b	b	b	b
	b	b	b	b	b	b	b	b	b	b	b	b

TABLE EX-20B

Output Head Configuration (spot pattern)- Rows: 36 Spots/Row: 1
Corresponding Figures: FIGs. 69,70Vertical Adjustment: 12 lines
Pattern of Spots:MultiRamp EffectiveVerticalSpotSpacing:1 line
Scan Pass:3 Blank=b EffectiveHorizontalSpotSpacing:3 dots

	Gi	Gj	Gk	Gl	Bi	Bj	Bk	Bl	Ri	Rj	Rk	Rl
	Be	Bf	Bg	Bh	Re	Rf	Rg	Rh	Ge	Gf	Gg	Gh
	Ra	Rb	Rc	Rd	Ga	Gb	Gc	Gd	Ba	Bb	Bc	Bd
Line	time t1					Dot Locations						
1												1
2											b	
3										b		
4									b			
5								b				
6							b					
7						b						
8					b							
9				b								
10			b									
11		b										
12	b											
13												1
14											b	
15										b		
16									b			
17								b				
18							b					
19						b						
20					b							
21				b								
22			b									
23		b										
24	b											
25												1
26											b	
27										b		
28									b			
29								b				
30							b					
31						b						
32					b							
33				b								
34			b									
35		b										
36	b											

TABLE EX-20C

Output Head Configuration (spot pattern) - Rows: 36 Spots/Row: 1
Corresponding Figures: FIGs. 69,70 VerticalAdjustment:12 lines
Pattern of Spots:MultiRamp EffectiveVerticalSpotSpacing:1 line
Scan Pass:3 Blank=b EffectiveHorizontalSpotSpacing:3 dots

	Gi	Gj	Gk	Gl	Bi	Bj	Bk	Bl	Ri	Rj	Rk	Rl
	Be	Bf	Bg	Bh	Re	Rf	Rg	Rh	Ge	Gf	Gg	Gh
	Ra	Rb	Rc	Rd	Ga	Gb	Gc	Gd	Ba	Bb	Bc	Bd
Line	time t16					Dot Locations						
1												16
2											13	
3										10		
4									7			
5								4				
6							1					
7						b						
8					b							
9				b								
10			b									
11		b										
12	b											
13												16
14											13	
15										10		
16									7			
17								4				
18							1					
19						b						
20					b							
21				b								
22			b									
23		b										
24	b											
25												16
26											13	
27										10		
28									7			
29								4				
30							1					
31						b						
32					b							
33				b								
34			b									
35		b										
36	b											

TABLE EX-20D

Output Head Configuration (spot pattern)- Rows: 36 Spots/Row: 1
Corresponding Figures: FIGs. 69,70 VerticalAdjustment:12 lines
Pattern of Spots:MultiRamp EffectiveVerticalSpotSpacing:1 line
Scan Pass:3 Blank=b EffectiveHorizontalSpotSpacing:3 dots

	Gi Be Ra	Gj Bf Rb	Gk Bg Rc	Gl Bh Rd	Bi Re Ga	Bj Rf Gb	Bk Rg Gc	Bl Rh Gd	Ri Ge Ba	Rj Gf Bb	Rk Gg Bc	Rl Gh Bd
Line	time t34					Dot Locations						
1												34
2											31	
3										28		
4									25			
5								22				
6							19					
7						16						
8					13							
9				10								
10			7									
11		4										
12	1											
13												34
14											31	
15										28		
16									25			
17								22				
18							19					
19						16						
20					13							
21				10								
22			7									
23		4										
24	1											
25												34
26											31	
27										28		
28									25			
29								22				
30							19					
31						16						
32					13							
33				10								
34			7									
35		4										
36	1											

Fiber-based Beam Coupling

As discussed previously, our invention permits several important applications of fiber-based beam coupling, several of which are synergistic with advantages resulting from other aspects of our invention. For example, the use of fiber and multiple line scanning as in our invention allow the use of multiple lasers per color, one laser of each color per line. In addition, time combining allows multiple lasers of a given color per line as shown in FIG. 19. Alone or in combination this permits us to use smaller, perhaps much more economical lasers and modulators within our system. Fiber-based beam coupling allows us to achieve similar ends differently or to pursue synergistic gains, for instance, using several blue lasers that are combined either before or after modulation using fiber-based beam coupling techniques to achieve the blue power levels required of a single line. Thus, we may achieve the advantages of multi-line scanning and fiber without having to adopt a 4x6 output head, for example. Further, as will be described in Example 21, fiber-based beam coupling also allows us to efficiently form composite ("white") beams to illuminate the dots of a given line. In FIGs 20, 21 and 22 we show configurations of an exemplary two-row system where several smaller lasers of a given color are combined before their respective modulators. In FIG. 20, the beams of red lasers 322, 323, 324 and 325 are of slightly different wavelengths, perhaps 631 nm, 633 nm, 635 nm, and 637 nm, respectively, and are inserted into fibers 43 and the beams are combined using Wavelength Division Multiplexing (WDM) combiner 229 into fibers 43 without leaving the fiber environment. In FIG. 21, the beams from lasers 22 are inserted in fibers 43 and then combined via fiber-based beam combiners 29 using other well known techniques that do not require differences in wavelength. The light from the fibers 43 then emerges into free space and is thence collimated into modulators 42. In FIG. 22, polarization combining optics 129 are used to combine the beams of two pairs of lasers 22.

In FIG. 23 we show another configuration with multiple lasers per color per row and fiber-based beam coupling, only in this example combining occurs after each of the beams has been separately modulated by modulators 32, which would preferably be fiber modulators 232. For clarity, only one fiber 42 is shown. Such a configuration might take advantage of emerging fiber modulation technology where inexpensive modulators operate directly on the beam in the fiber, but which cannot withstand higher power levels. This configuration also allows for the use of diode lasers where the lasers themselves are modulated by either pulsing or varying the input power to them.

FIGs. 24 and 25 both show configuration in which both pre-modulator and post-modulator combination is used to advantage. FIG. 24 is an exemplary one-line system, while FIG. 25 demonstrates some of the breadth and flexibility of our invention in the context of a four-line system. This latter example employs one large green laser 24 capable of supplying power to all four lines, its beam being split using either dichroic optics or fiber-based splitters 129 into fibers 43, 16 red diode lasers 422, each of which is power modulated as described above and then launched into fibers 42, with groups of four then combined using fiber-based couplers into fibers 42, and eight blue lasers 26. The blue lasers are combined using either fiber-based combiners or, as shown, polarizing combiner cubes 129 with the aid of half wave plates 329, two before each of four modulators 32, after which the light is launched into fibers 42. This figure further shows the modulated beams in 12 fibers 42 being combined into four fibers 42, each with three primary colors, by combiners 29, to form the output head 58 of Example 21.

In the foregoing, we have discussed combining the light from two or more fibers into one fiber, and have referred to WDM as being useful in combining (or splitting) beams of different wavelengths. WDM can be used for combining widely different wavelengths, such as red, green, and blue, or for combining beams of very slightly different wavelengths, as shown in FIG. 20. Other techniques well known in the communications industry are

generally not dependent upon wavelength variations, and multiple beams of either the same or different wavelengths may be combined. These are described in texts such as Introduction to Fiber Optics, Ghatak and Thyagarajan, Cambridge University Press, 1998 and include such techniques as fiber gratings, fused taper couplers, shaved block couplers, as well as others. Note that, as opposed to the polarizing beam splitter/combiners shown in FIG. 22 and the dichroics used in prior art laser projectors, both WDM and other fiber-based beam coupling techniques can be used to combine more than two beams of the same or nearly the same color, usually by cascading 2 : 1 couplers.

These and other fiber-based beam coupling techniques are included in our invention as well as the use of dichroics and other conventional combining optics, either alone or in combination with fiber and/or fiber-based beam couplers in combination with fiber. There are also other techniques emerging that will accomplish these same goals and could be used to advantage in our invention.

EXAMPLE 21

As discussed previously, it may be advantageous to combine the separately modulated beams of the colors destined for a single row into a single fiber emitting end. FIG. 6 shows an alternate embodiment of elements of the spot projection, modulation and laser sections 40, 30, and 20, respectively, of FIG.1 that might be effective for such a purpose. The colored beams for a given row are modulated by modulators 32, inserted individually into fibers 42, and the beams from each red-green-blue group of the 12 fibers 42 are combined by fiber-based coupler 29 into one of the fibers 42 terminating in one of emitting ends 56. The advantage of this technique is that the width of the pattern of spots on the screen is reduced compared with prior Examples, allowing for less blanking time between scan passes, giving somewhat more brightness. This approach also preserves the relatively low power levels within the modulators and at the fiber tips where the insertion of higher power laser beams is most likely to cause damage. Further, and as described

previously, this fiber-based combination is much more efficient than techniques of prior art laser projectors which generally use dichroics.

This Example 21 illustrates a four row by one emitting end per row output head, as shown in FIG.7, projecting a pattern of spots as shown in FIG. 7S, and employing fiber-based combination of the different color beams to form composite beams, using such an exemplary system as shown in FIG.6. As further described in Tables EX-21A, EX-21B and Figures 72 through 74, the combination of separately modulated beams of more than one color into a single fiber terminating in an emitting end and emitting such combined beams as a single effective beam from such emitting end as heretofore described for our invention yields a simplified system similar to the ramp system having a one line effective row spacing in an effective 4 row by 1 emitting end or spot per row.

TABLE EX-21A

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 1
Corresponding Fig: FIGs.7,72 Vertical Adjustment: 4 lines
Blank = b Effective Vertical Spacing: 1 lines

Scan Pass	Lines Written by Respective Spots			
	RGBa	RGBb	RGBc	RGBd
1	1	2	3	4
2	5	6	7	8
3	9	10	11	12
:	:	:	:	:
268	1069	1070	1071	1072
269	1073	1074	1075	1076
270	1077	1078	1079	1080

Each spot illuminated by the combined color beams emitted from an emitting end of a row is indicated by RGBa, RGBb, RGBc or RGBd. The line reordering shown in Table EX-21A and FIGs. 72A-72D is a simple successive four line adjustment for progressive scanning, producing no overlap at the top and bottom of the screen. Further, the width of the array and corresponding spot pattern is reduced in comparison with the ramp array of Example

TABLE EX-21B

Output Head Configuration (spot pattern)- Rows: 4 Spots/Row: 1
Corresponding Figures: FIGs. 7,YY Vertical Adjustment: 4 lines
Pattern of Spots: Ramp Effective Vertical Spot Spacing:1 line
Scan Pass:1 Blank=b Effective Horizontal Spot Spacing: 3

	RGBa	RGBb	RGBc	RGBd
Line	time t1	Dot Locations		
1	1			
2		b		
3			b	
4				b
Line	time t4	Dot Locations		
1	4			
2		1		
3			b	
4				b
Line	time t7	Dot Locations		
1	7			
2		4		
3			1	
4				b
Line	time t10	Dot Locations		
1	10			
2		7		
3			4	
4				1
Line	time t1920	Dot Locations		
1	1920			
2		1917		
3			1914	
4				1911
Line	time t1923	Dot Locations		
1	b			
2		1920		
3			1917	
4				1914
Line	time t1926	Dot Locations		
1	b			
2		b		
3			1920	
4				1917
Line	time t1929	Dot Locations		
1	b			
2		b		
3			b	
4				1920

15, the overlap on either side of the screen at the beginning and end of each scan pass is reduced, as shown in FIGs. 73A - 73H. As with the discussion relating to Examples 14-16, the linear array has added flexibility in accomodating changes in resolution and aspet ratio.

It should be noted that using fiber-based beam coupling to emit combination beams from each emitting end can be employed for any number of rows having a single emitting end per row, even for only one row. Referring to FIGs. 7 and 7S, it is within the potential scope of our invention to employ an output head having only the emitting end identified as Row A. In this case, the advantages derived from using multi-line scanning or sweeping would not be realized, but if advances in scanning technology solve many of the problems previously outlined, such a system might be possible.

The use of fiber-based beam combining can also be applied to the other emitting end configurations described herein and that may occur to those skilled in the art with the benefit of this disclosure of our invention. For instance, in Example 1, illustrating the line reordering and time combining for a 4 row by 3 emitting ends per row output head configuration, described in Tables EX-1A and Tables EX-1B,1C and schematically shown in FIGs. 28A-28H, we assumed an effective row spacing of about 3 lines. If an output head configuration of 4 rows by 1 emitting end per row is employed, with the fibers arranged in a log array, the line reordering is substantially the same as shown in EX-1A. However, the time combination of colors shown in Tables EX-1B,1C is now unnecessary. With the log arrangement shwon in FIGs. 71 and 71S there will be overlap at the ends of the horizontal line writing scan passes, as shown in FIGs. 74A-74D. If a brick arrangement is employed, the line reordering remains the same, although all other things such as fiber diameter being equal, at a greater effective row spacing than for the log arrangement. Further with the brick arrangement, the overlap at the ends of

each scan pass is eliminated, but with consequent increased overlap at the top and bottom.

The reduced size of the array possible with fiber-based beam combining may also be used to advantage for more than four rows of a single emitting end configuration to achieve even greater resolution. This and other advantages and applications of our invention disclosed herein may occur to others after a full consideration of the possibilities inherent in our conception of the use of fiber emitting ends in combination with multiple line scanning, as illustrated most recently herein using fiber-based beam combining techniques.

We claim:

1. A system for projecting an image onto a surface, comprising:

at least two light beams;

at least two optical fibers, each optical fiber adapted to emit at least one of the light beams from an emitting end thereof;

a scanner to direct the light beams emitted from the emitting ends of the optical fibers to substantially simultaneously illuminate desired different dot locations on the viewing surface.

2. The system as in claim 1 wherein said light beams are modulated.

3. The system as in claim 1 or 2 wherein said scanner is a raster scanner.

4. The system of claim 1, 2 or 3 wherein at least two of the light beams are of substantially different wavelengths.

5. The system of claim 4 wherein at least two of the different wavelengths each approximate one of the primary colors.

6. The system of claim 4 or 5 wherein at least two of the light beams are of substantially the same wavelength.

7. The system of claim 1, 2, 3, 4, 5 or 6 wherein said scanner is movable during at least one scan pass of a desired duration to direct the light beams to illuminate separate locations along at least one desired scan path along said viewing surface.

8. The system of claim 7 wherein said emitting ends and said scanner are configured such that during at least one scan pass at least two of the light beams illuminate substantially the same dot locations along the same scan path on the viewing surface at different times.

9. The system of claim 7 or 8 wherein said emitting ends and said scanner are configured such that during at least one scan pass at least two of the light beams illuminate locations along at least two separate scan paths on the viewing surface.

10. The system of claim 7, 8 or 9 wherein said scanner is further movable during at least one frame pass of a desired duration to direct the light beams in a direction transverse of the scan paths between the beginning of at least two scan passes such that at least two different scan paths are illuminated during different scan passes.

11. The system of claim 10 wherein the movement of said scanner in the direction transverse of the scan path is substantially continuous during a scan pass.

12. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or 11 further comprising at least one focusing optic positioned to focus at least two of such light beams simultaneously.

13. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12 wherein said at least one focusing optic is positioned between the emitting ends and the scanner.

14. The system of claim 12 or 13 wherein said at least one focusing optic is a single optic.

15. The system of claim 12, 13 or 14 wherein said at least one focusing optic focusses the light beams through said scanner in a two-dimensional pattern of spots on the viewing surface corresponding to the configuration of the emitting ends.

16. The system of claim 12, 13, 14 or 15 wherein said at least one focusing optic includes a mirror.

17. The system of claim 12, 13, 14 or 15 wherein said at least one focusing optic includes a holographic element.

18. The system of claim 12, 13, 14 or 15 wherein said at least one focusing optic includes a lens.

19. The system of claim 18 wherein said lens is an achromat.

20. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 or 19, wherein the number of fiber ends into which light beams are inserted equals the number of emitting ends from which such light beams are emitted.

21. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 or 19, wherein the number of fiber ends into which light beams are inserted differs from the number of emitting ends from which such light beams are emitted.

22. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or 21 wherein at least two of said light beams are emitted from one of said emitting ends as a combined beam.

23. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 or 22, further comprising:

at least one source of such light beams;

at least one modulator for modulating at least one of such light beams; and

at least one inserter adapted to insert at least one light beam from said at least one source into at least one optical fiber;

said scanner including

a line scanning component adapted to direct the at least two light beams emitted from said emitting ends to illuminate the desired scan paths during each scan pass of a frame pass, and

a frame scanning component adapted to redirect each of the at least two light beams emitted from said emitting ends in a direction transverse of the scan paths to successively illuminate different desired scan paths during a frame pass.

24. The system of claim 23 wherein the number of sources of light beams differs from the number of emitting ends from which such light beams are emitted.

25. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 or 24 wherein at least one light beam is divided using a fiber-based beam coupler into at least two light beams, each of which is emitted from one of said emitting ends.

26. The system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 or 25 wherein at least two light beams are combined into one combined beam using a fiber-based beam coupler into one optical fiber.

27. The system of claim 26 wherein the combined light beam within said one optical fiber is combined with a light beam in at least one other optical fiber to form another combined light beam for emission from an emitting end of the emitting ends.

28. The system as in claim 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 or 25 wherein at least two of said light beams are unmodulated when inserted into said fibers.

29. The system of claim 28 wherein at least two of such unmodulated light beams are combined using a fiber-based beam coupler into at least one of said fibers.

30. The system of claim 29 wherein the combined unmodulated light beam within said one at least one optical fiber is combined with at least one light beam in at least one other optical fiber.

31. The system of claim 28 wherein at least one of such unmodulated light beams is divided using a fiber-based beam coupler into at least two unmodulated light beams.

32. The system of claim 31 wherein at least one of the divided unmodulated light beams is divided to form at least two additional unmodulated light beams.

33. The system of claim 29, 30, 31 or 32 wherein said unmodulated beams are modulated prior to being directed to the viewing surface by said scanner.

34. A system for projecting an image onto a viewing surface, comprising:

at least two light beams,

a scanner adapted to direct the light beams onto the viewing surface to form a pattern of spots on the viewing surface;

the light beams being directed to the viewing surface by the scanner such that the spots of the pattern of spots illuminate at least two substantially separate lines of an array of desired dot locations to be illuminated on the viewing surface during each of a succession of scan passes during a frame pass, wherein at substantially the same time during at least one scan pass, at least one spot of the pattern of spots illuminates a dot location of such array that is not adjacent to the dot location illuminated by any other spot of the pattern of spots.

35. The system of claim 34 wherein such light beams are directed by the scanner such that at substantially the same time during at least one scan pass, at least one spot of the pattern of spots illuminates a dot location of such array that is not adjacent to the dot location in the same line of dot locations illuminated by any other spot of the pattern of spots.

36. The system as in claim 34 or 35, wherein at substantially the same time during at least one scan pass, at least one spot of the pattern of spots illuminates a dot location of such array that is not adjacent to the dot location in a different line of dot locations illuminated by any other spot of the pattern of spots.

37. The system of claim 34, 35 or 36 wherein at least three of such light beams are in a positional configuration with respect to each other and collectively directed to the viewing surface by said scanner such that the pattern of spots on said viewing surface is two-dimensional.

38. The system of claim 37 wherein the pattern of spots on the viewing surface corresponds to the configuration of the light beams.

39. The system of claim 34, 35, 36, 37 or 38 wherein during a frame pass at least one spot scanned to illuminate at least one line of dot locations during one scan pass of such frame pass is not scanned to illuminate any line of dot locations adjacent to such one line of dot locations during any other scan pass of such frame pass.

40. The system of claim 34, 35, 36, 37, 38 or 39 wherein said scanner is a raster scanner.

41. The system of claim 34, 35, 36, 37, 38, 39 or 40 wherein the pattern of spots is swept during a scan pass by a single scanning section.

42. The system of claim 34, 35, 36, 37, 38, 39, 40 or 41 wherein at some time during a scan pass at least one line is incomplete while another line is complete.

43. The system of claim 34, 35, 36, 37, 38, 39, 40, 41 or 42, further comprising:

at least one source of the light beams;

said scanner including

a line scanning component adapted to substantially simultaneously direct the light beams to move the pattern of spots in a line direction along the line of dot locations on the viewing surface during the scan passes, and

a frame scanning component adapted to direct the light beams to move the pattern of spots in a frame direction transverse of the line direction such that the line of dot locations of the pattern of spots are at different

locations on the viewing surface at the initiation of each successive scan pass during the applicable frame pass.

44. The system of claim 43, further comprising:

a modulator adapted to modulate each light beam directed by said scanner to the viewing surface.

an input signal having intensity and color values for pixels of each frame corresponding to the desired dot locations on the viewing surface; and

a controller adapted to initiate the illumination of a dot location on the viewing surface by releasing a modulation signal to the modulator for a selected light beam at a time during an applicable scan pass of a frame pass to produce a spot of a desired color and intensity;

said controller further adapted to order the intensity and color values of the input signal for each frame to release the modulation signal when the scanner directs a beam of the light beams to illuminate a spot at a dot location corresponding to a pixel position in the input signal.

45. The system claimed in claim 44 wherein said controller is further adapted to cause the illumination of a location along at least one line of dot locations with a spot corresponding to the intensity and color value of the input signal, and to cause the illumination of the same location with another light beam directed along the same line at a different time.

46. The system of claim 34, 35, 36, 37, 38, 39, 41, 42, 43, 44 or 45 wherein movement of the patten of spots in the frame direction is substantially continuous during scan passes.

47. The system of claim 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45 or 46 wherein at least two of the spots of the pattern of spots illuminating dot locations along at least one of the lines of dot locations during at least one scan pass are of substantially the same wavelength.

48. The system of claim 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46 or 47 wherein at least two of the spots of the pattern of spots illuminating at least one of the lines of dot locations during at least one scan pass are of substantially different wavelengths.

49. The system of claim 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47 or 48 wherein at least two of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least two rows of at least one spot per row, and the spots of each row illuminate locations along a different line of dot locations on the viewing surface.

50. The system of claim 49 wherein at least three of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least three rows of at least one spot per row.

51. The system of claim 49 wherein at least four of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least four rows of at least one spot per row.

52. The system of claim 49 wherein at least twelve of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least twelve rows of at least one spot per row.

53. The system of claim 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47 or 48 wherein at least four of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least two rows of at least two spots per row, and the spots of each row illuminate a plurality of the same locations along at least one separate line of dot locations on the viewing surface at different times.

54. The system of claim 53 wherein at least twelve of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least four rows of at least three spots per row.

55. The system of claim 53 wherein at least sixteen of the light beams are directed to the viewing surface by said scanner such that the pattern of spots has at least four rows of at least four spots per row.

56. A method for projecting an image onto a viewing surface, comprising the steps of:

illuminating desired dot locations of an array of such desired dot locations on the viewing surface with a pattern of at least two spots wherein at substantially the same time at least one spot of the pattern of spots illuminates a dot location of such array that is not adjacent to the dot location illuminated by any other spot of the pattern of spots;

sweeping such pattern of spots in a line direction along at least two different lines of such desired dot locations on the viewing surface during a scan pass;

adjusting the position of the pattern of spots in a frame direction transverse of the line direction; and

repeating the sweeping and adjusting steps a desired number of times to write a frame.

57. The method of claim 56 wherein at least one spot of the pattern of spots illuminates a dot location of such array that is not adjacent to the dot location in the same line of dot locations illuminated by any other spot of the pattern of spots.

58. The method of claim 56 or 57 wherein at least one spot of the pattern of spots illuminates a dot location of such array that is not adjacent to the dot location in a different line of dot locations illuminated by any other spot of the pattern of spots.

59. The method of claim 56, 57 or 58 wherein the pattern of spots is two-dimensional on said viewing surface.

60. The method of claim 56, 57, 58 or 59 wherein during at least one sweeping step at least one spot of the pattern of spots does not illuminate any dot location in at least one line of dot locations that is adjacent to another line of dot locations illuminated by such spot during the same frame.

61. The method of claim 56, 57, 58, 59, or 60 wherein said adjusting step is substantially continuous during substantially all sweeping steps of a frame.

62. The method of claim 56, 57, 58, 59, 60 or 61 wherein at some time during a scan pass all dot locations in at least one line of dot locations have not been completely illuminated by at least one spot while all dot locations in another line of dot locations have been illuminated by at least one other spot.

63. The method of claim 56, 57, 58, 59, 60, 61 or 62 wherein during the sweeping step at least two of the spots swept along at least one line of dot locations are of substantially different wavelengths.

64. The method of claim 56, 57, 58, 59, 60, 61, 62 or 63 wherein during the sweeping step at least two of the spots swept along at least one line of dot locations are of substantially the same wavelengths.

65. The method of claim 56, 57, 58, 59, 60, 61, 62, 63 or 64 wherein at least one of the sweeping steps during a frame further comprises:

sweeping at least one spot of the pattern of spots along at least one line of dot locations on the viewing surface that is located between at least two lines of dot locations on the viewing surface that were swept by at least one spot of the pattern of spots during prior sweeping steps during the writing of the frame.

66. The method of claim 56, 57, 58, 59, 60, 61, 62, 63, 64 or 65 wherein all lines of desired dot locations on the viewing surface are illuminated by at least one spot of the pattern of spots during the writing of the frame.

67. The method of claim 56, 57, 58, 59, 60, 61, 62, 63, 64, 65 or 66 wherein during at least one sweeping step of a frame at least one of the spots of the pattern of spots substantially overwrites at least one dot location of a line of dot locations swept by another of said spots of the pattern of spots during the same or another sweeping step.

68. The method of claim 56, 57, 58, 59, 60, 61, 62, 63, 64, 65 or 66 wherein during at least one sweeping step of a frame at least one of the spots of the pattern of spots substantially overwrites at least one dot location of a line of dot locations swept by at least two other spots of the pattern of spots during at least two other and/or same sweeping steps.

69. The method of claim 67 or 68 wherein the spot overwriting such dot location has a substantially different wavelength than the spot illuminating such dot location during another sweeping step.

70. The method of claim 67, 68 or 69 wherein the spot overwriting such dot location has a substantially different wavelength than the spot illuminating such dot location during another sweeping step.

71. The method of claim 67, 68, 69 or 70 wherein the spot overwriting such dot location has a substantially different wavelength than the spot illuminating such dot location during the same sweeping step.

72. The method of claim 67, 68, 69, 70 or 71 wherein the spot overwriting such dot location has substantially the same wavelength than the spot illuminating such dot location during the same sweeping step.

73. The method of claim 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71 or 72 wherein during each adjusting step, the spots of the pattern of spots are moved in the frame direction a number of adjacent lines of dot locations on the viewing surface for a frame that is substantially equal to the number of lines of dot locations illuminated by the spots of the pattern of spots during a majority of the sweeping steps during such frame.

74. The method of claim 73 wherein the number of adjacent lines of dot locations on the viewing surface is substantially equal to an integer multiple of the number of lines of dot locations illuminated by the spots of the pattern of spots during a majority of the sweeping steps during such frame.

75. The method of claim 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73 or 74, further comprising the steps of:

emitting the at least two light beams from at least one emitting end of at least one optical fiber in a configuration corresponding to the pattern of spots.

76. The method of claim 75, further comprising the step of:

focusing the light beams with a focusing optic after their emission.

77. A system for projecting an image onto a surface, comprising:

at least two light beams;

at least two optical fibers adapted to emit at least two of the beams from at least one emitting end thereof;

a scanner to direct the light beams emitted from the emitting ends of the optical fibers to substantially simultaneously illuminate desired different dot locations on the viewing surface.

78. The system of claim 77 wherein at least two of the light beams are emitted from a single emitting end.

79. The system of claim 77 or 78 wherein at least one of such light beams is modulated.

80. The system of claim 77, 78 or 79 wherein at least one of such light beams is unmodulated.

81. The system of claim 78, 79 or 80 wherein all of such light beams are modulated prior to being directed to the viewing surface by said scanner.

82. The system of claim 77, 78, 79, 80 or 81, further comprising:

at least three of such light beams;

at least three of such optical fibers adapted to emit at least three of the beams from at least two emitting ends thereof.

83. The system of claim 77, 78, 79, 80, 81 or 82 wherein at least one light beam is divided using at least one fiber-based beam coupler into at least two light beams.

84. The system of claim 77, 78, 79, 80, 81, 82 or 83 wherein at least two light beams are combined using at least one fiber-based beam coupler into at least one optical fiber.

85. The system of claim 84 wherein the combined light beam within said at least one optical fiber is combined with a light beam in at least one other optical fiber to form another combined light beam.

86. The system of claim 83 wherein at least one of the divided unmodulated light beams is divided to form at least two additional unmodulated light beams.

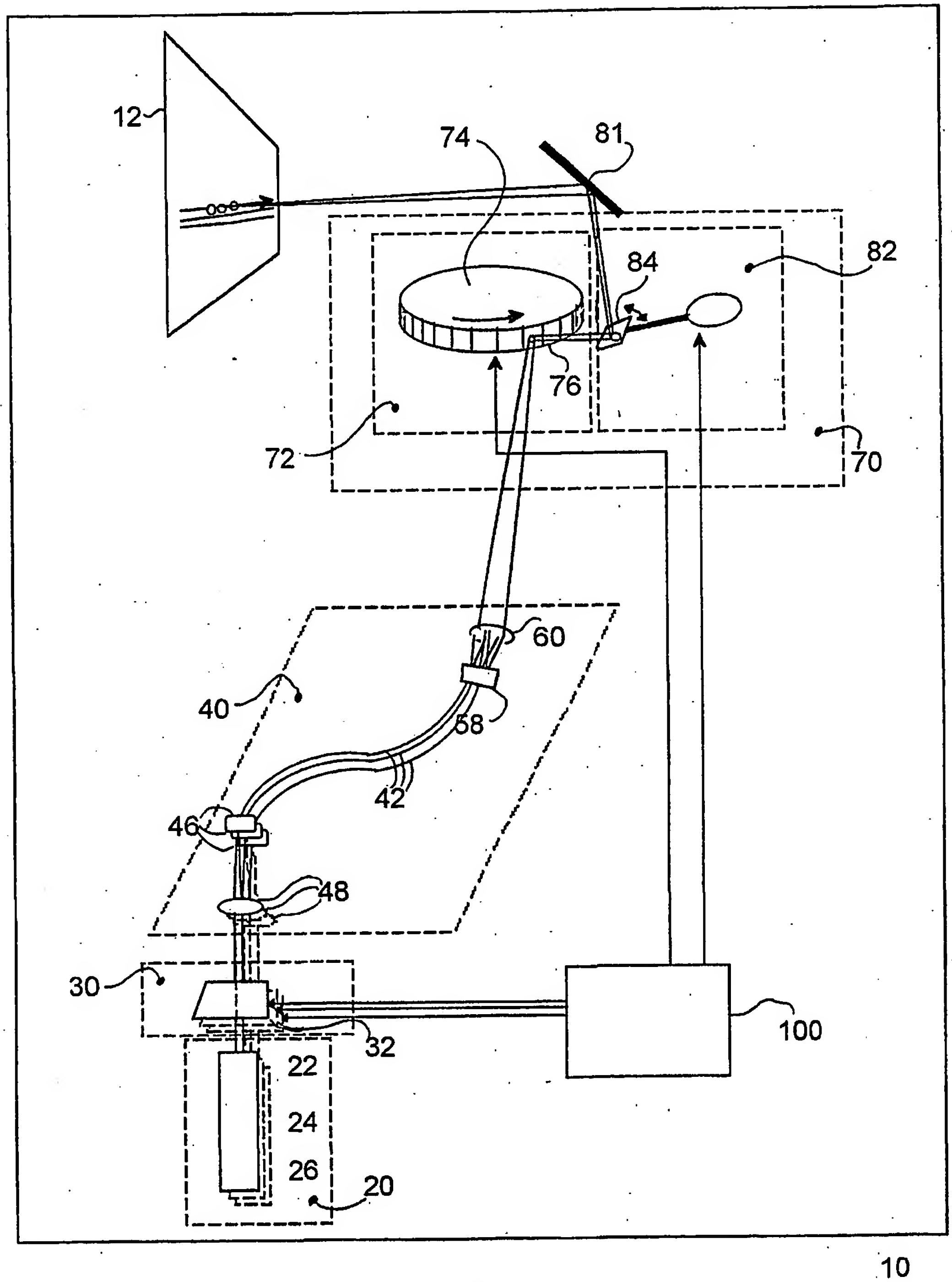


FIG. 1

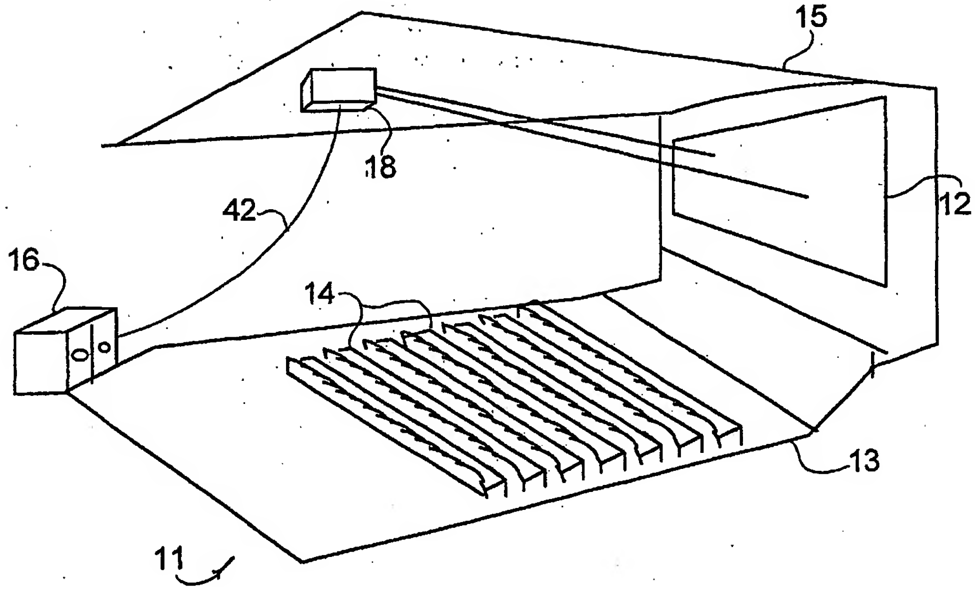


FIG. 2

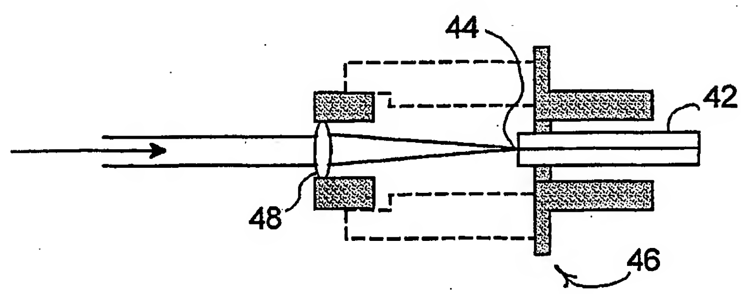


FIG. 3

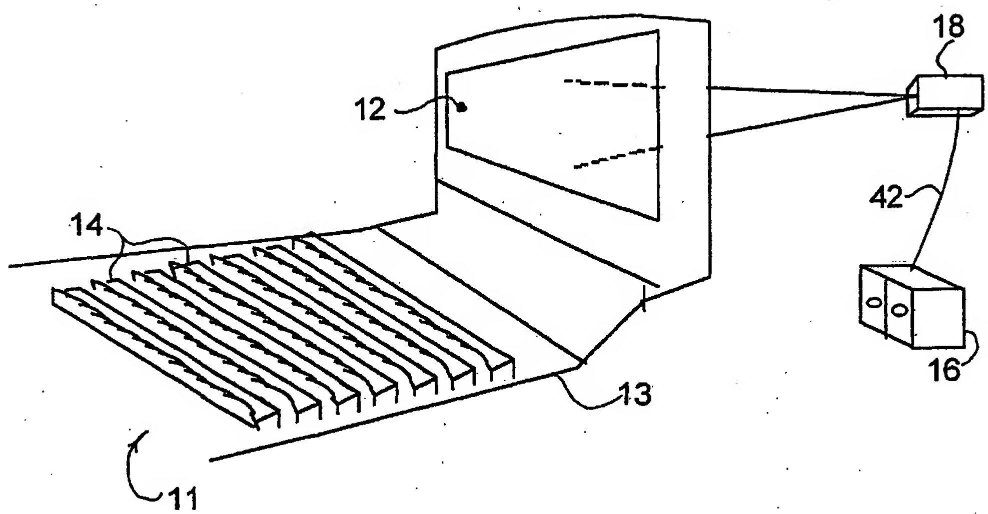


FIG. 4

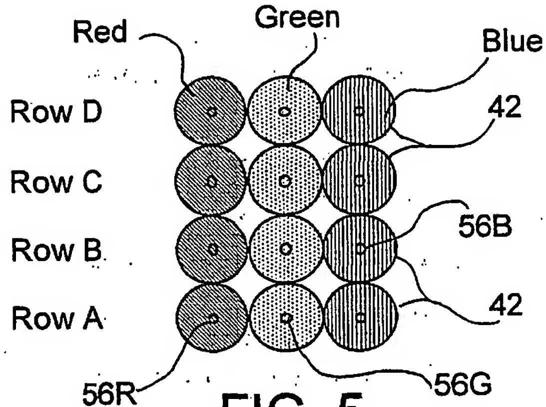

Red
Green
Blue
Row D
Row C
Row B
Row A
42
56B
42
56R
56G

FIG. 5

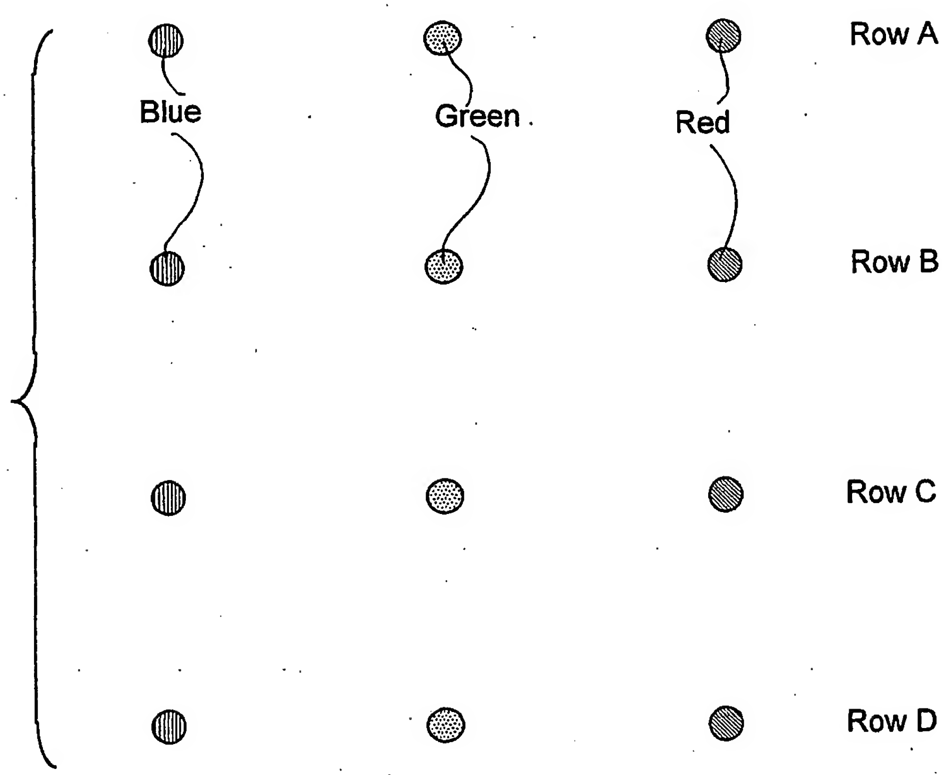
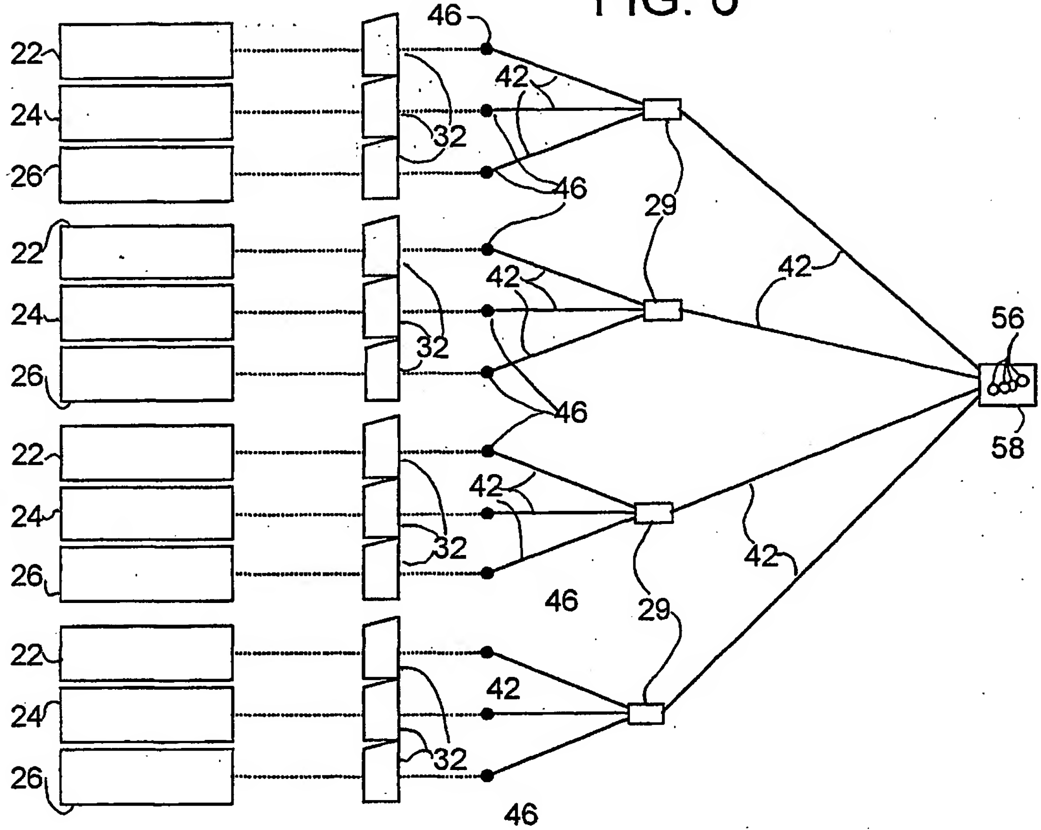

Row A
Blue
Green
Red
Row B
Row C
Row D

FIG. 5S

FIG. 6


46
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58

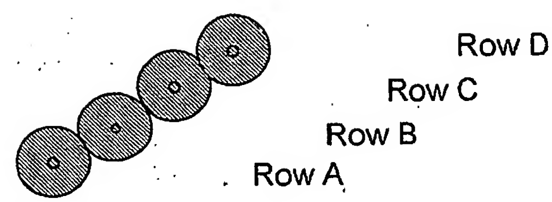


FIG. 7

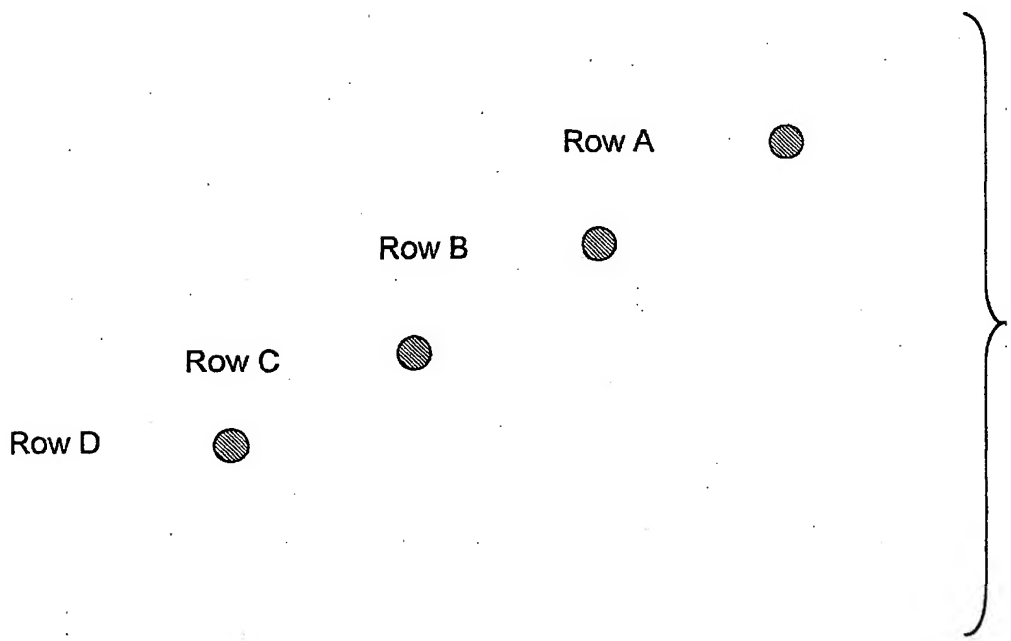


FIG. 7S

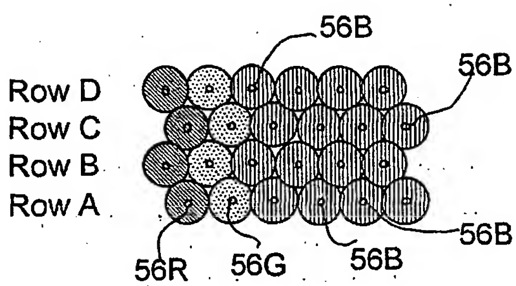

56B
56B
Row D
Row C
Row B
Row A
56B
56R
56G
56B

FIG. 8

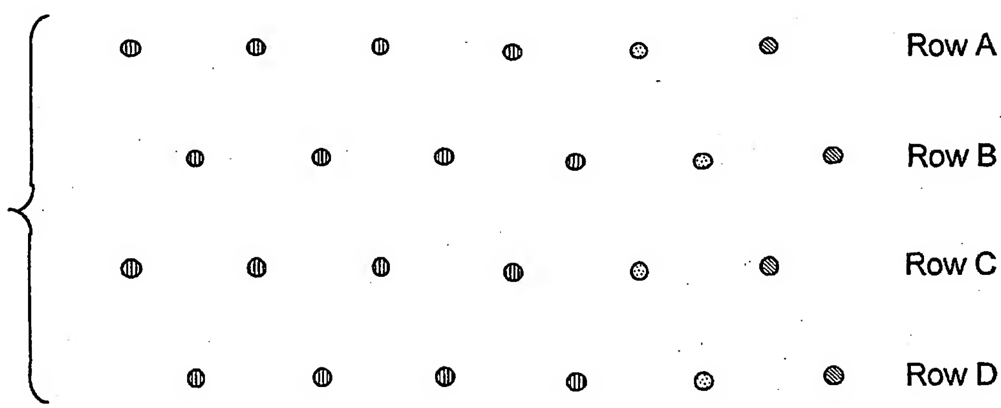

Row A
Row B
Row C
Row D

FIG. 8S

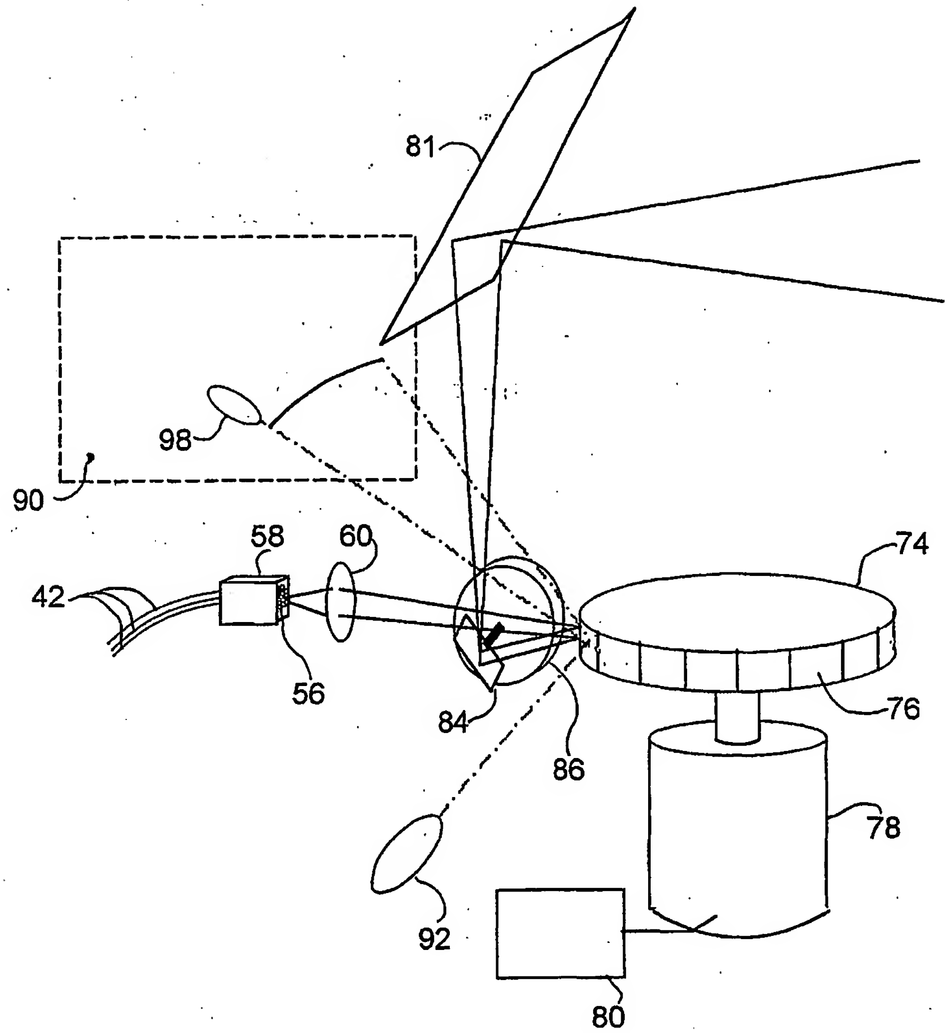


FIG. 9

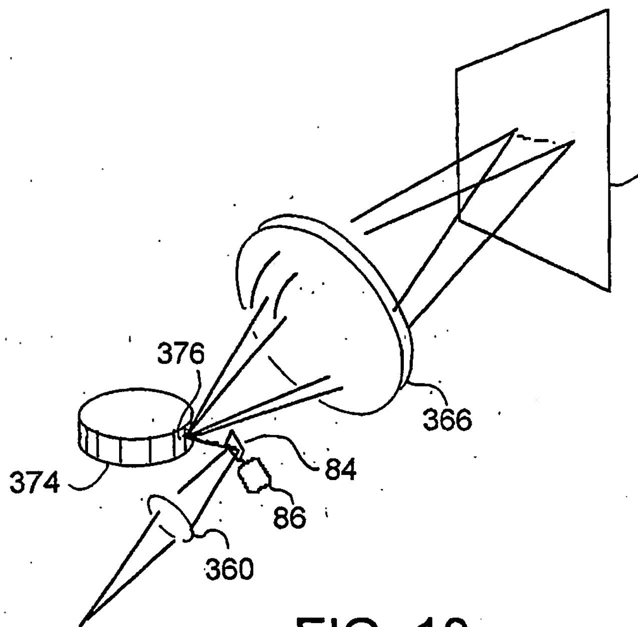


FIG. 10

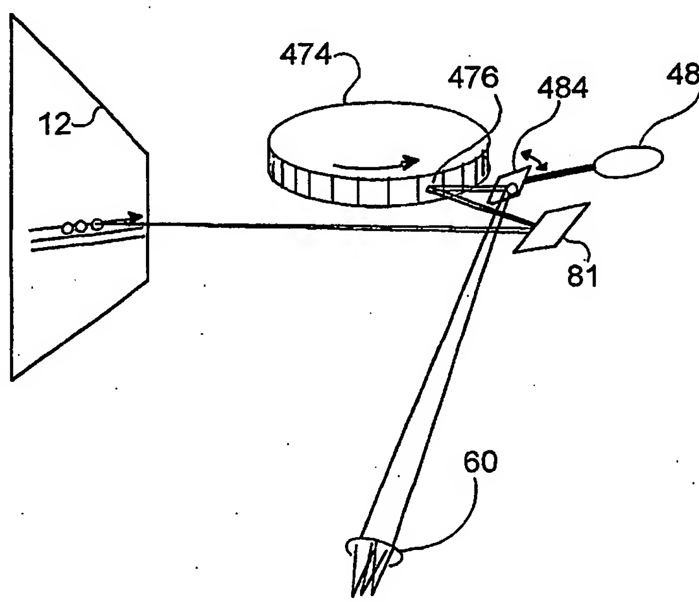


FIG. 11

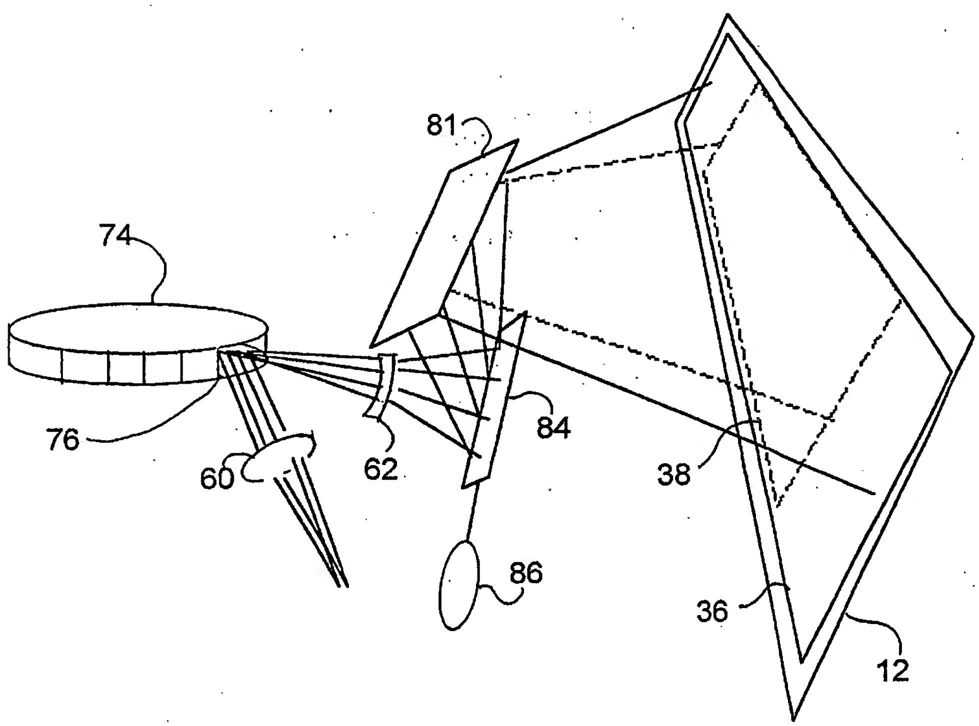


FIG. 12

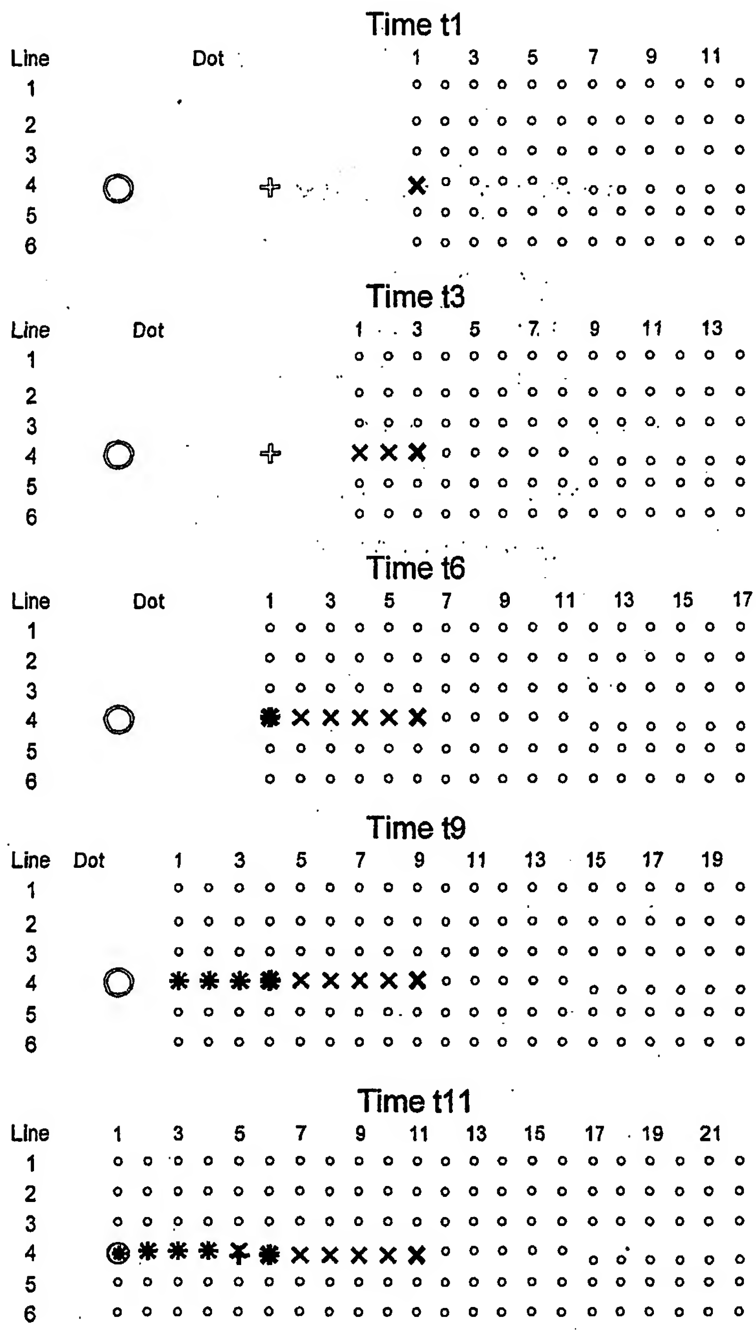


FIG. 13A

FIG. 13B

FIG. 13C

FIG. 13D

FIG. 13E

× red + green O blue ✱ red+green ⊛ red+green+blue

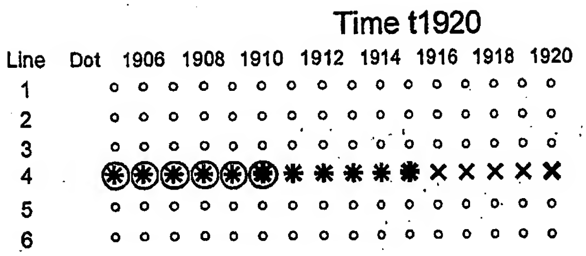


FIG. 13F

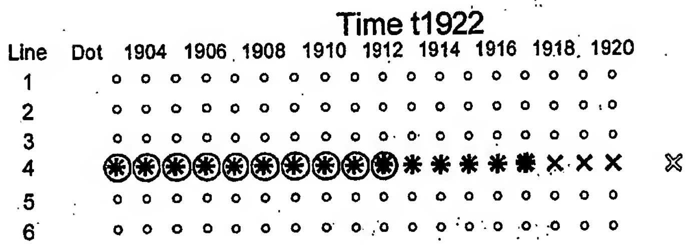


FIG. 13G

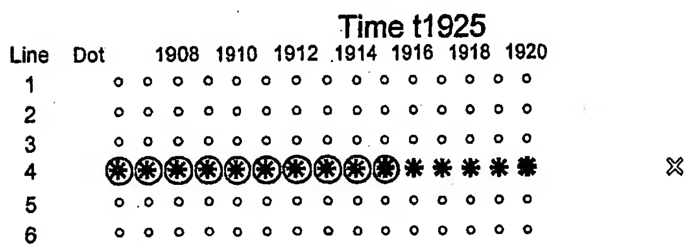


FIG. 13H

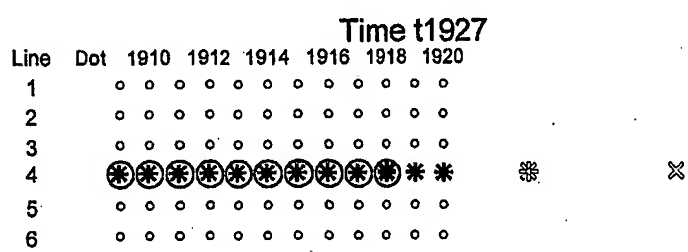


FIG. 13I

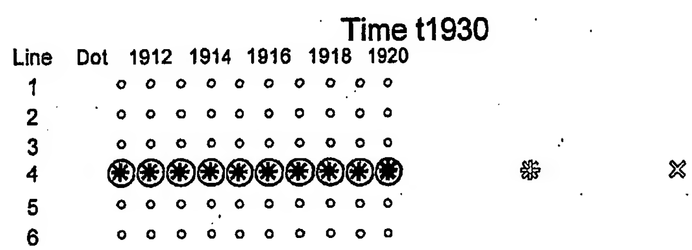


FIG.13J

× red + green O blue ✱ red+green ⊛ red+green+blue

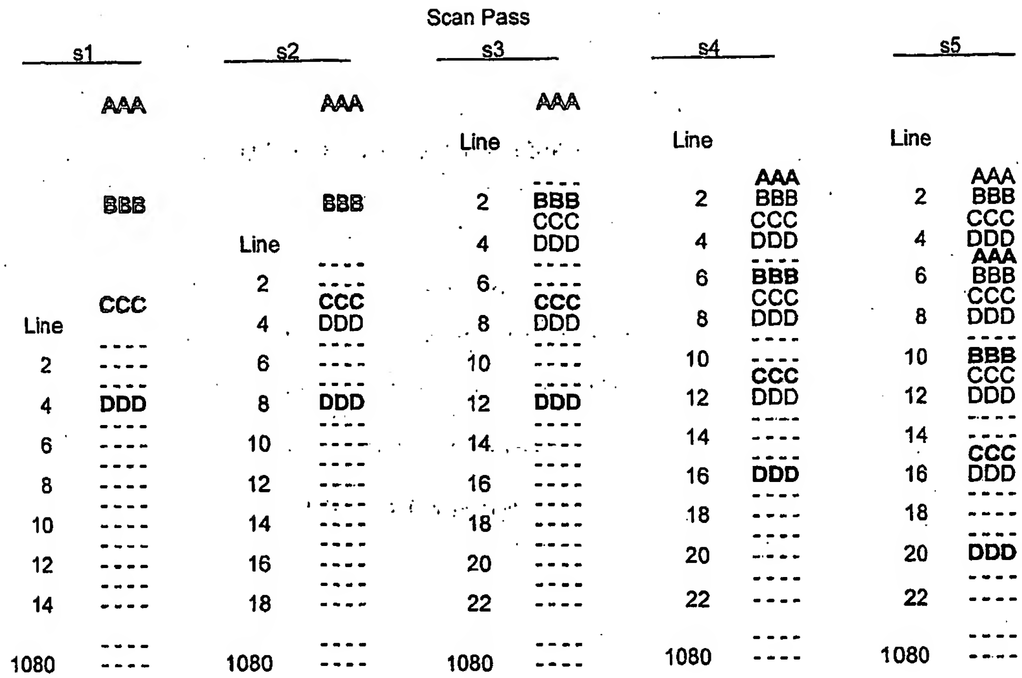


FIG.14A FIG.14B FIG.14C FIG.14D FIG.14E

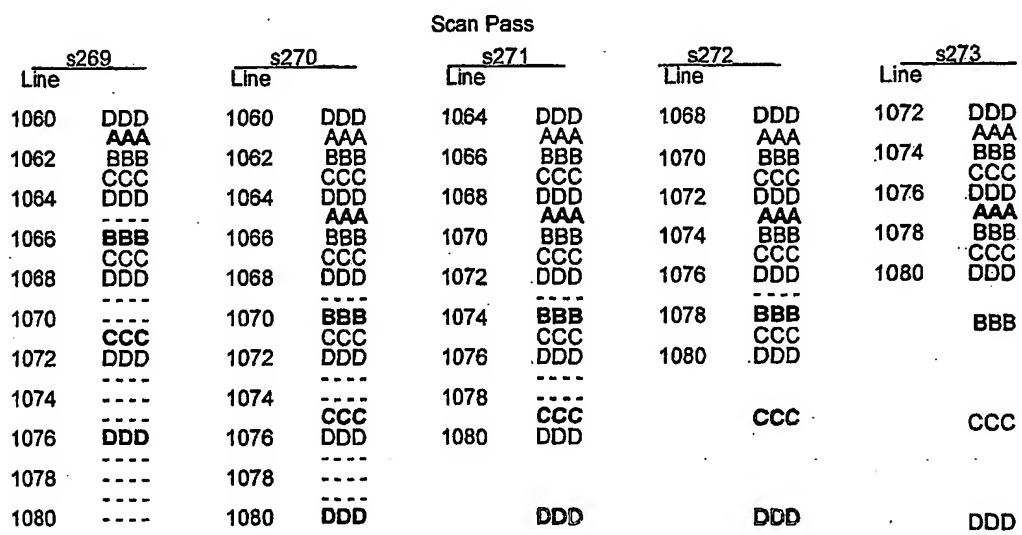


FIG.15A FIG.15B FIG.15C FIG.15D FIG.15E

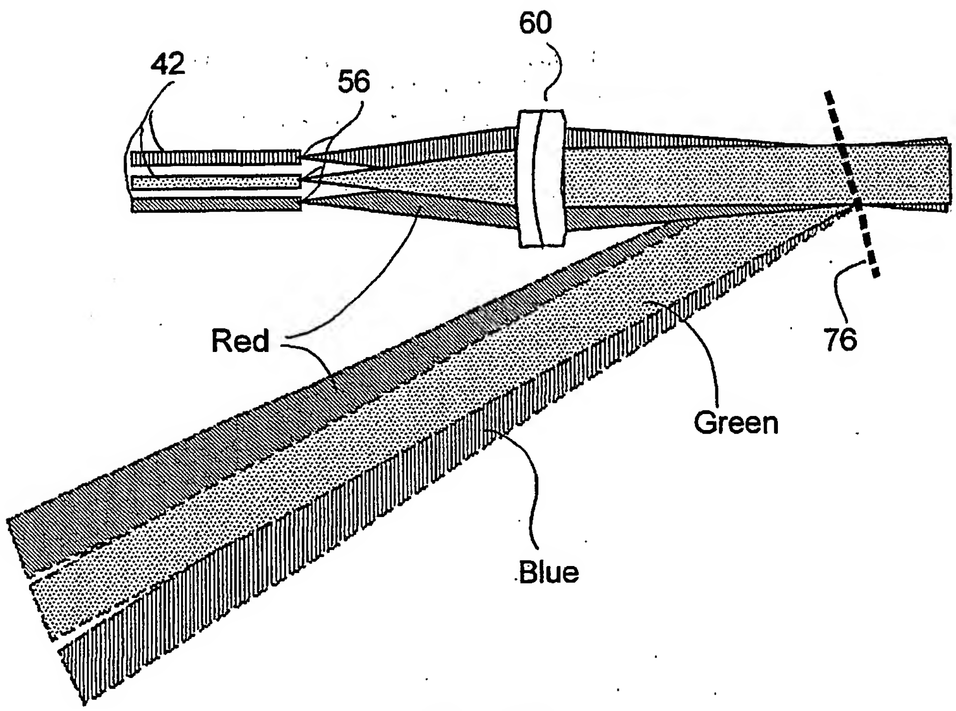
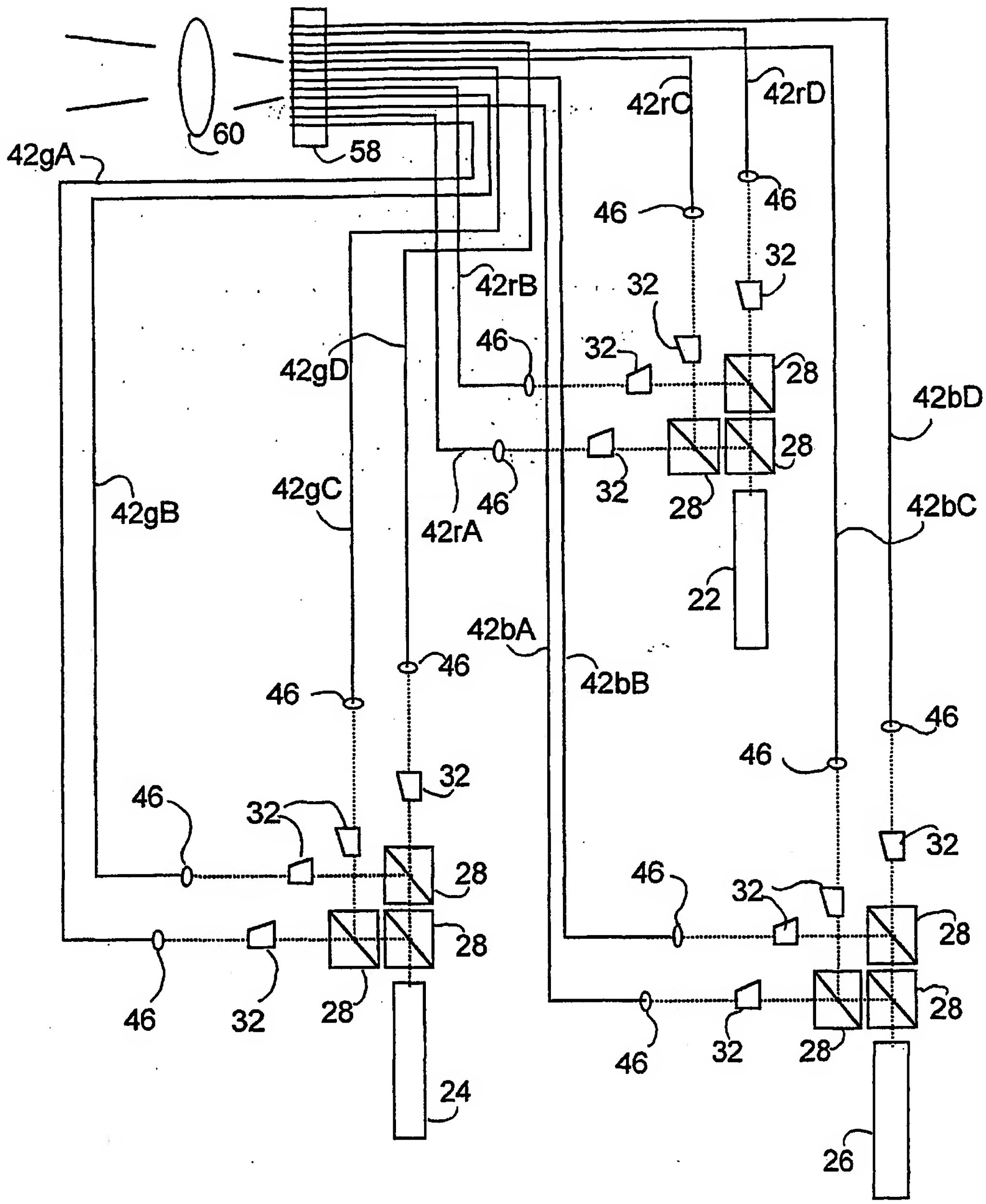


FIG. 16



60
58
42gA
42rC
42rD
46
46
32
32
42rB
32
46
42gD
28
42bD
28
32
42gB
42gC
46
42rA
28
42bC
22
42bA
42bB
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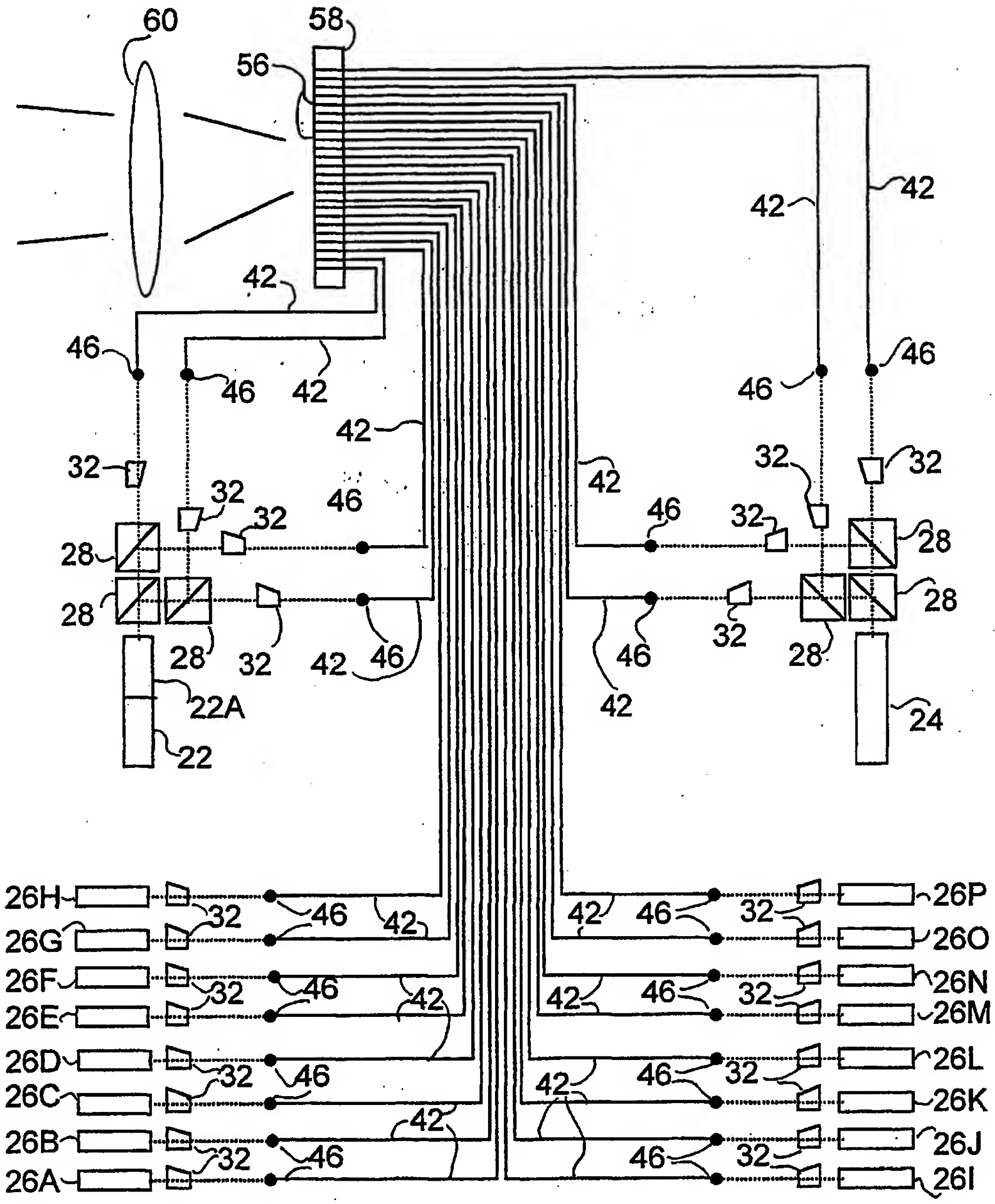
FIG. 17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22A
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26H
32
46
42
42
46
32
26P
26G
26O
26F
32
46
42
42
46
32
26N
26E
26M
26D
32
46
42
46
32
26L
26C
26K
26B
42
32
46
46
32
26J
26A
26I

FIG. 18

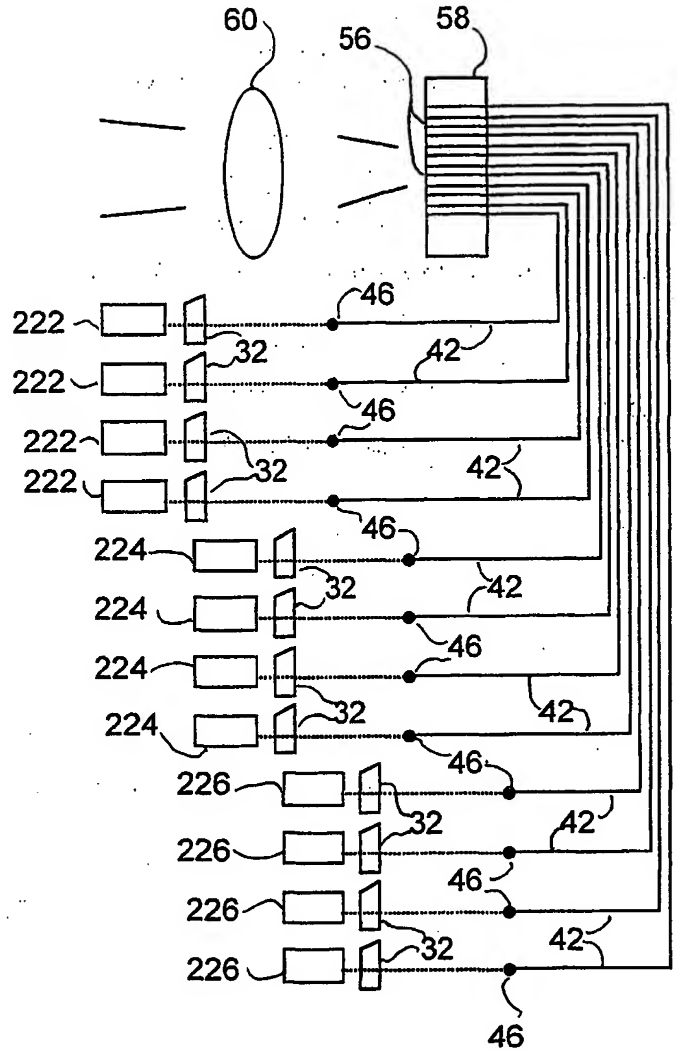
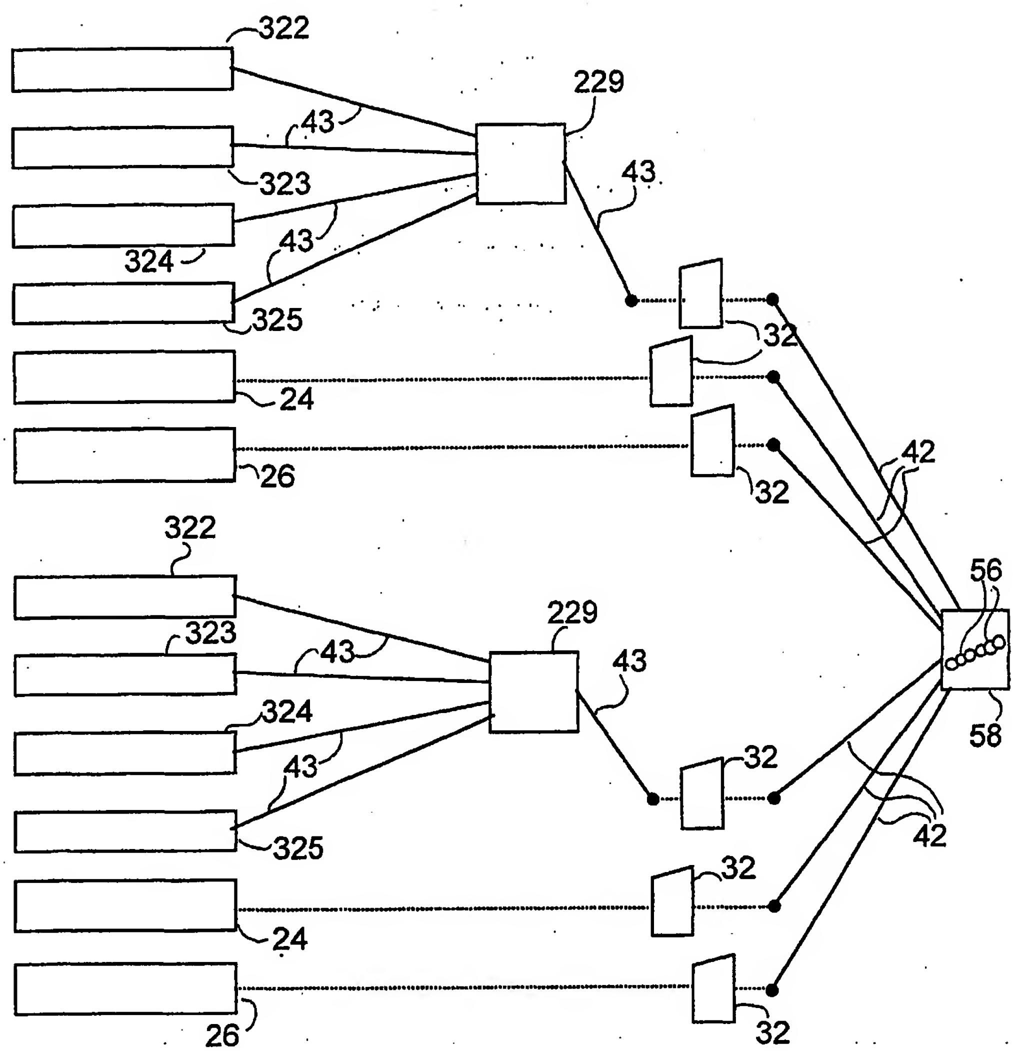


FIG. 19


322
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32
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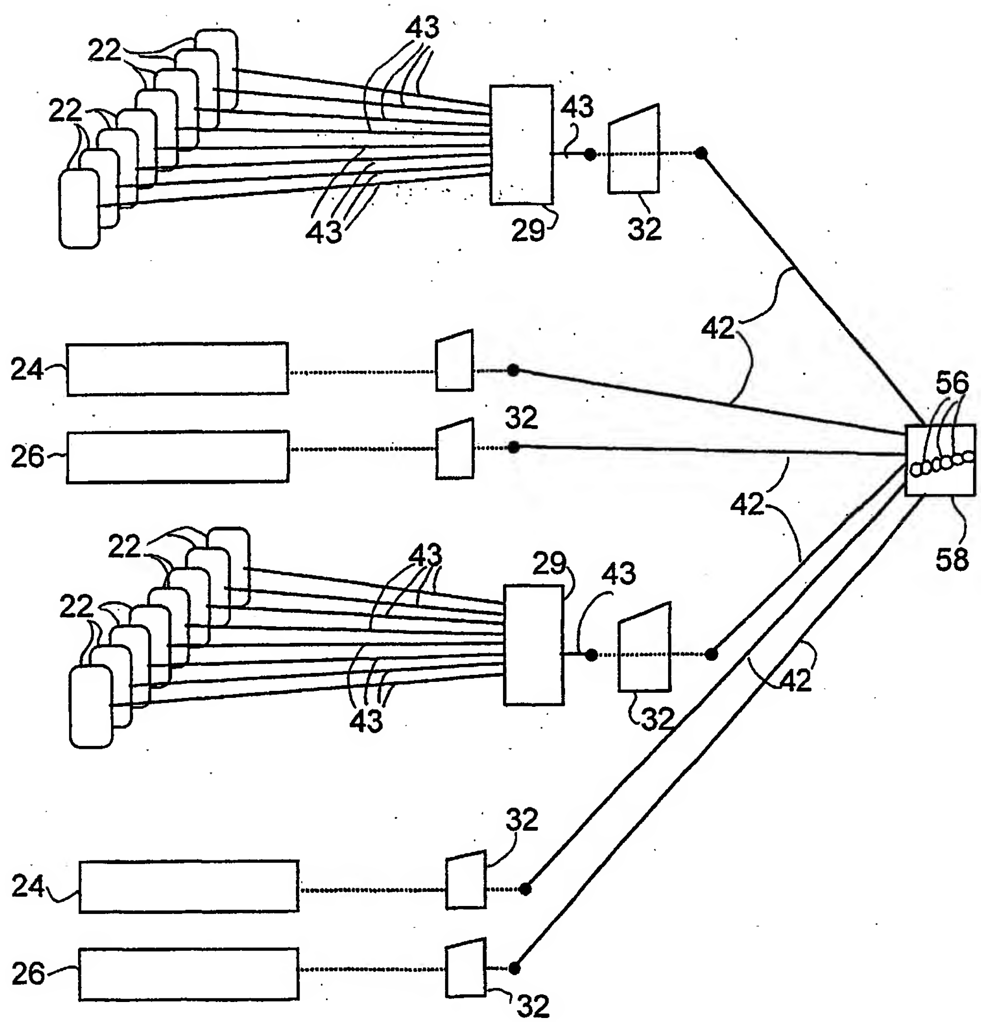
32

FIG. 20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32

FIG. 21

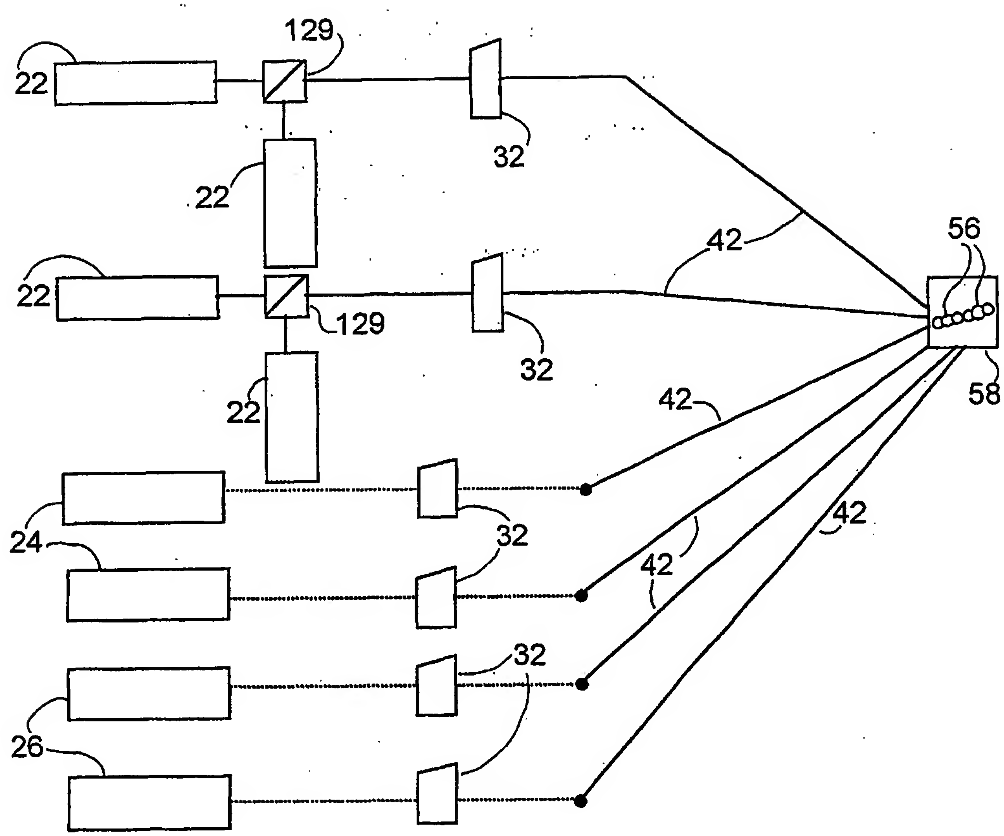


FIG. 22

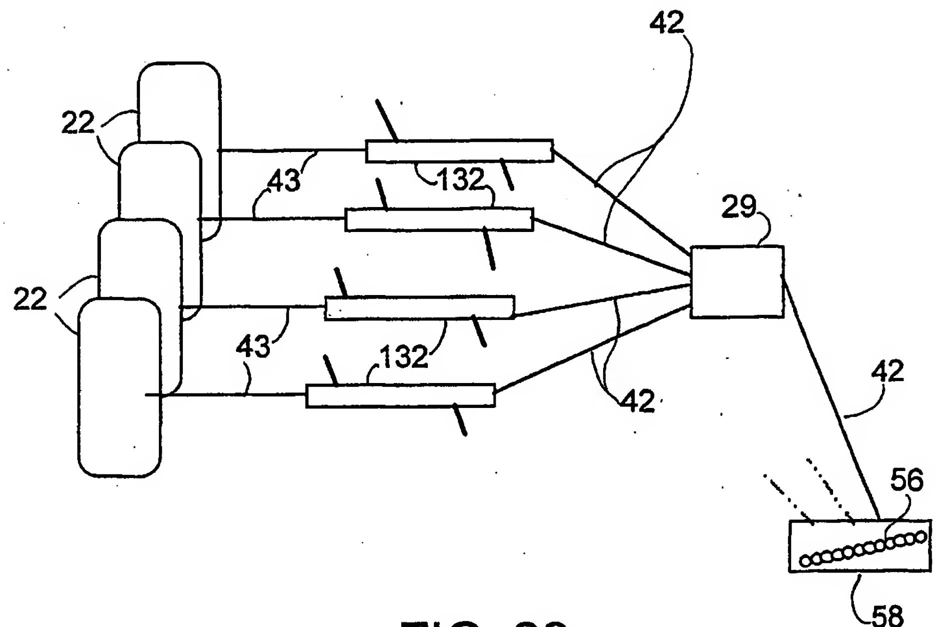


FIG. 23

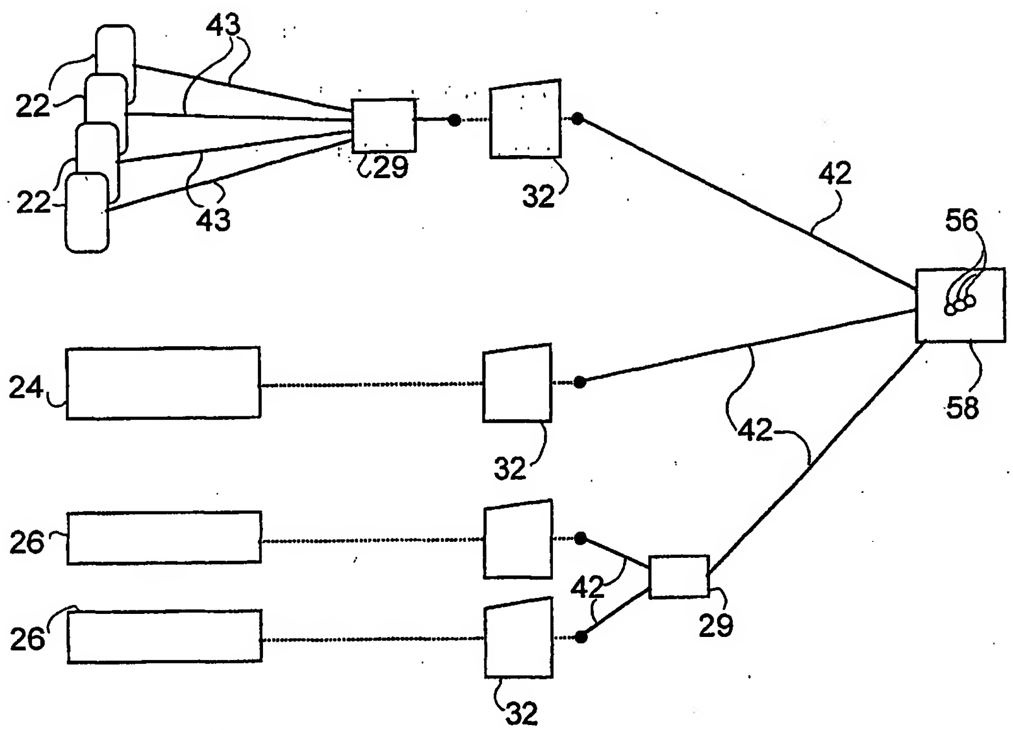
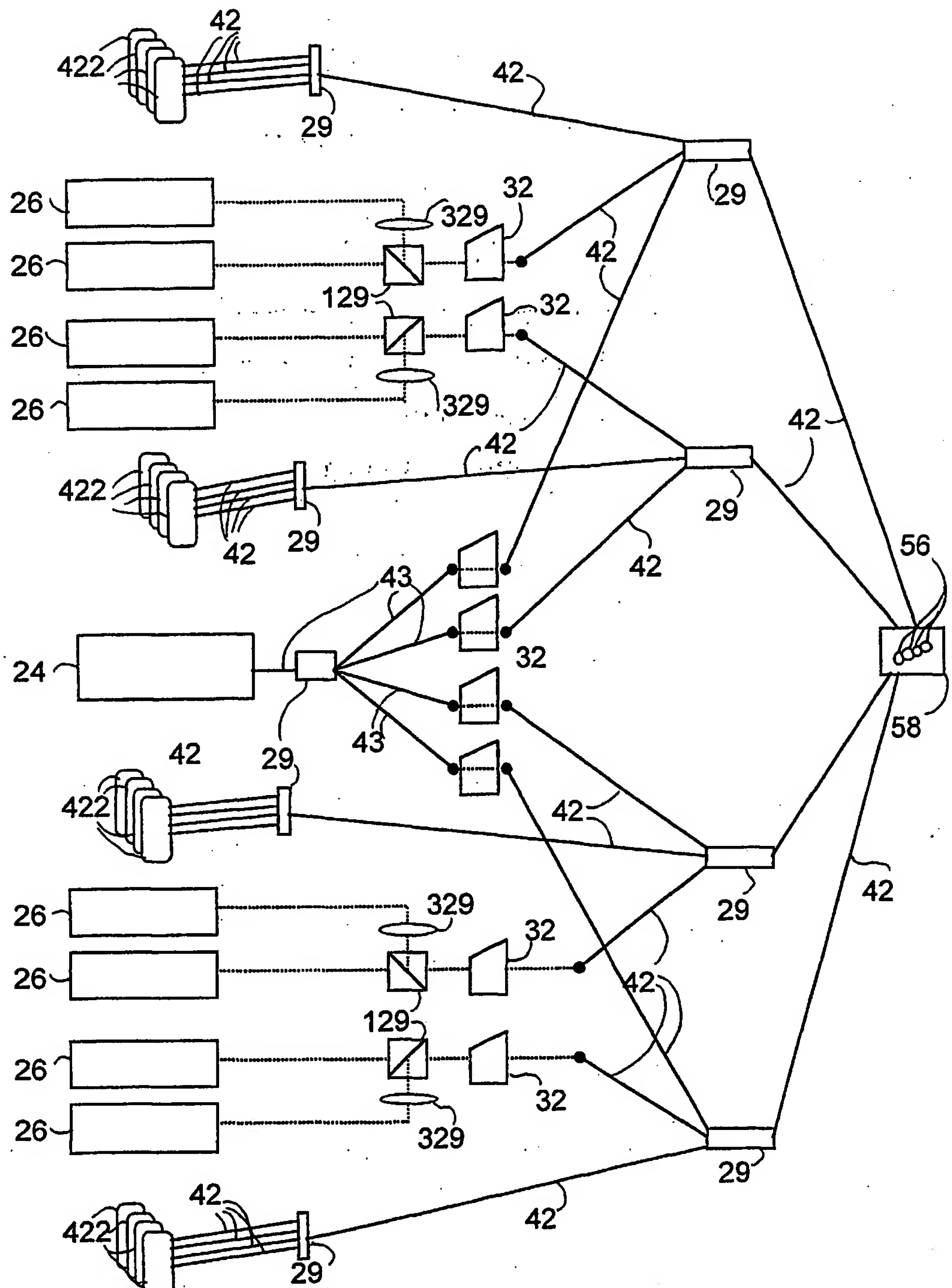


FIG. 24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422
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29
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129
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329
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422
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29
43
42
24
32
56
29
43
58
42
29
422
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329
32
129
42
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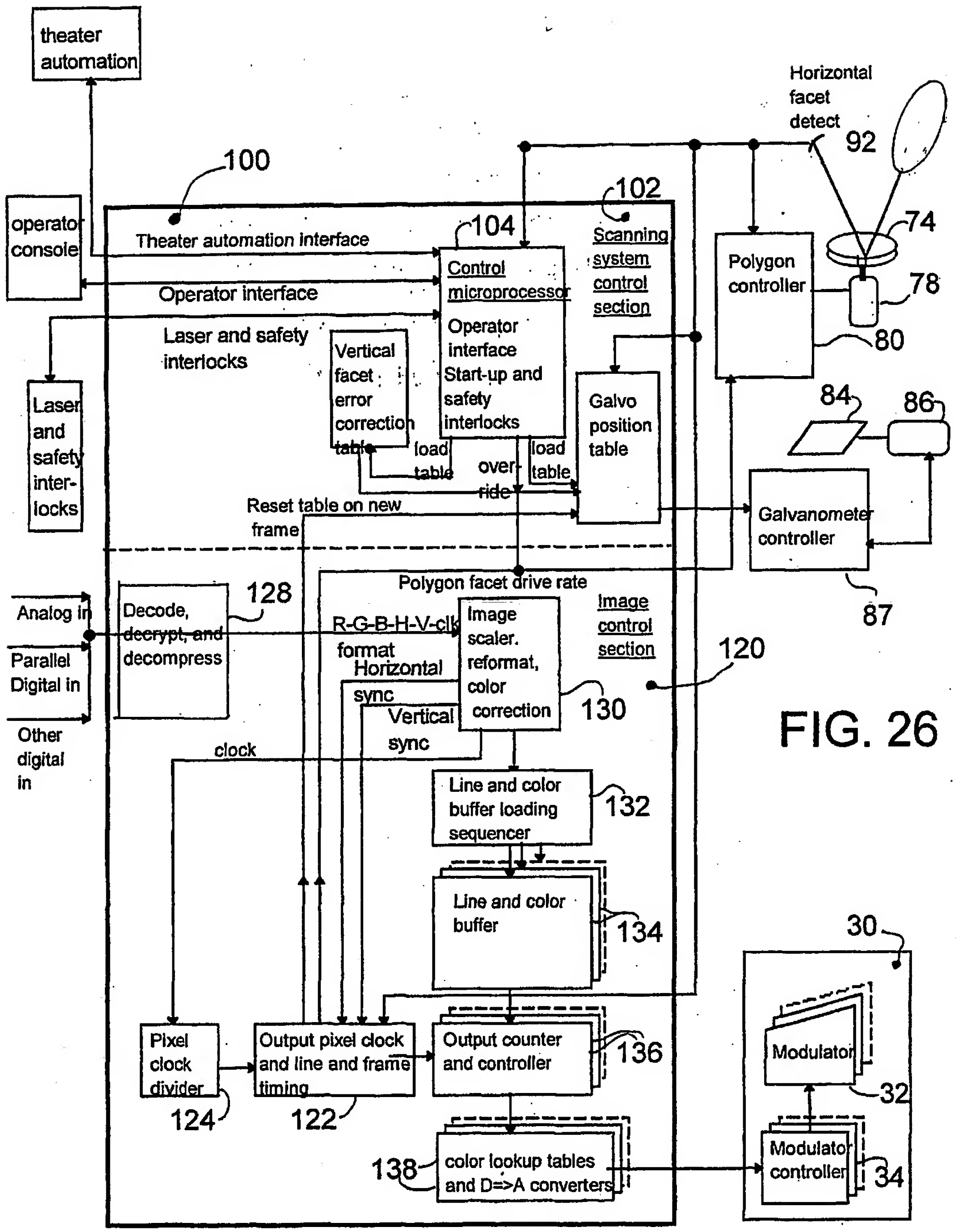
329
42
29
42
422
42
29

FIG. 25



theater automation
operator console
Laser and safety inter-locks
100
102
104
Theater automation interface
Operator interface
Laser and safety interlocks
Control microprocessor
Operator interface Start-up and safety interlocks
Scanning system control section
Vertical facet error correction table
load table
over-ride
load table
Galvo position table
Reset table on new frame
Horizontal facet detect
92
74
78
80
Polygon controller
84
86
Galvanometer controller
87
Polygon facet drive rate
Analog in
Parallel Digital in
Other digital in
Decode, decrypt, and decompress
128
R-G-B-H-V-clk format
Horizontal sync
Vertical sync
Image scaler, reformat, color correction
130
Image control section
120
clock
Line and color buffer loading sequencer
132
Line and color buffer
134
Pixel clock divider
124
Output pixel clock and line and frame timing
122
Output counter and controller
136
138
color lookup tables and D=>A converters
30
Modulator
32
Modulator controller
34

FIG. 26

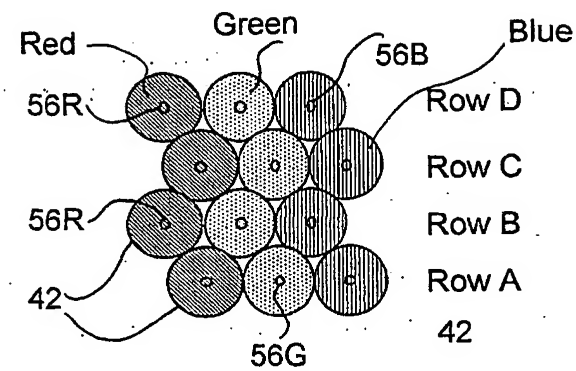


FIG. 27

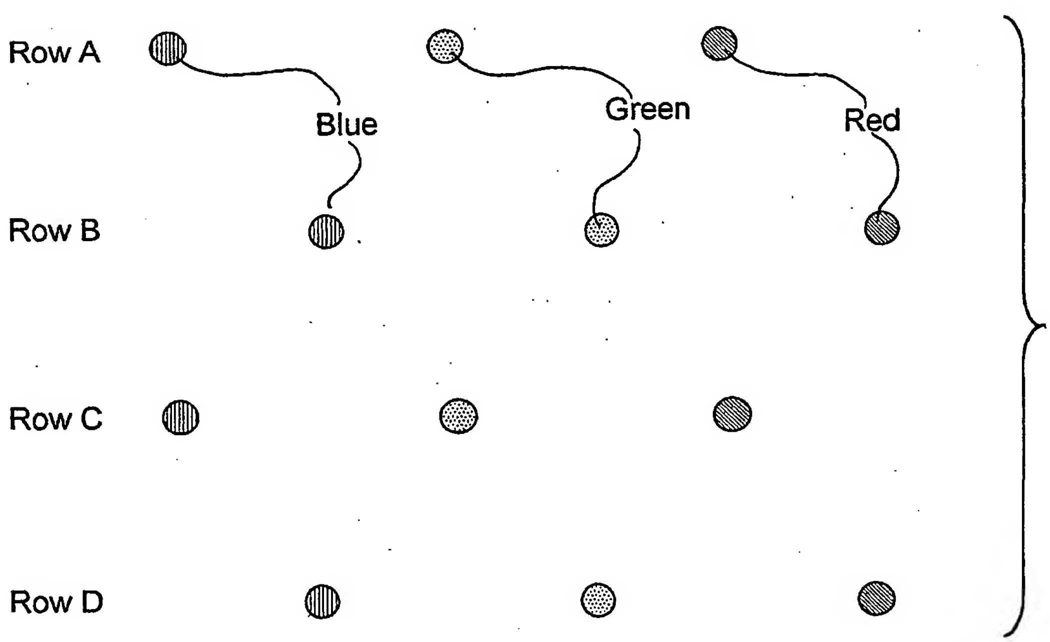
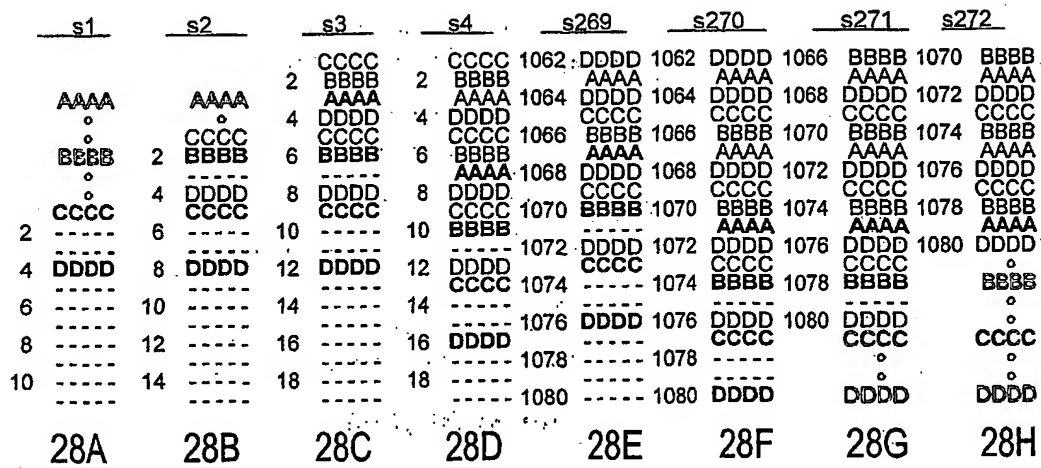
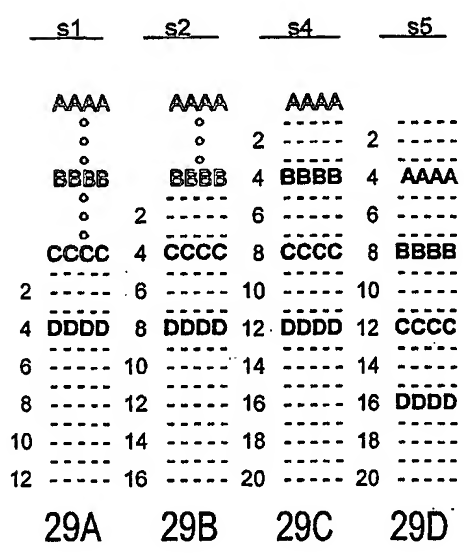


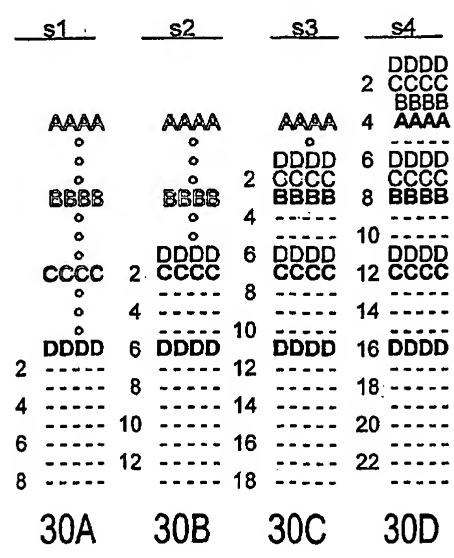
FIG. 27S



FIGs. 28A-28H



FIGs. 29A-29D



FIGs. 30A-30D

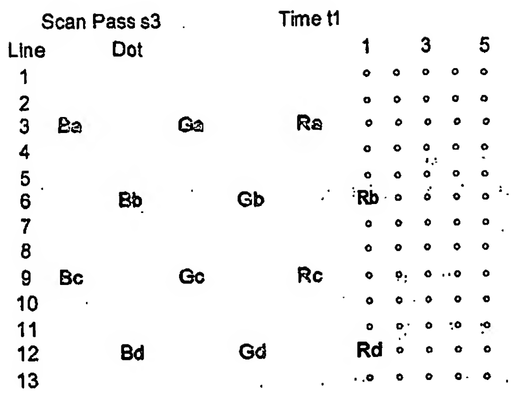


FIG. 31A

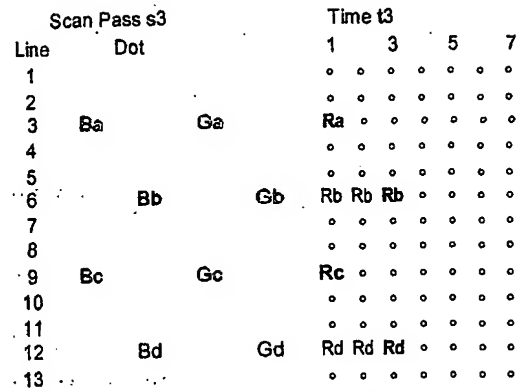


FIG. 31B

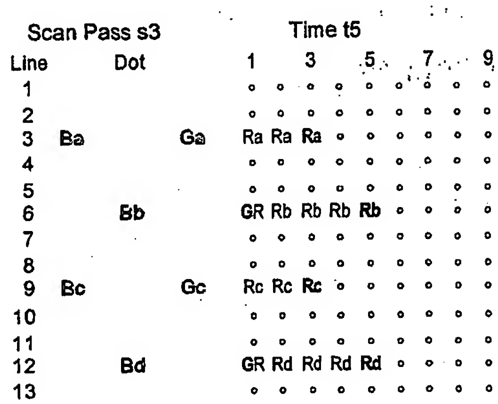


FIG. 31C

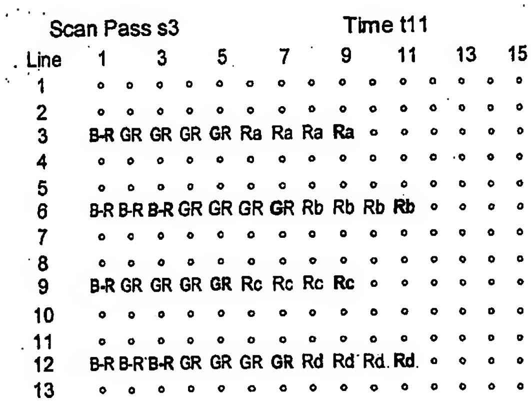


FIG. 31D

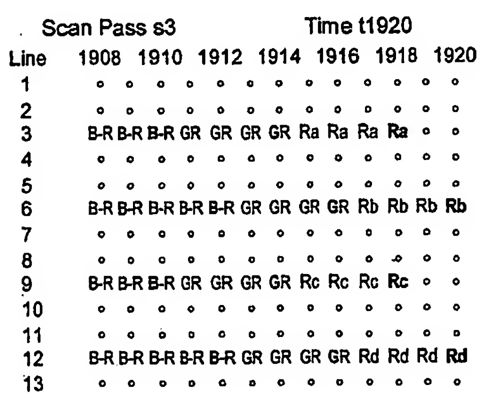


FIG. 31E

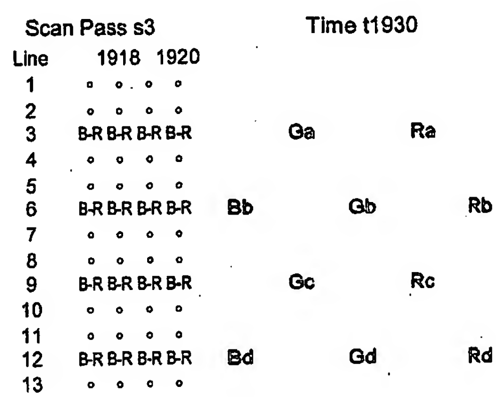
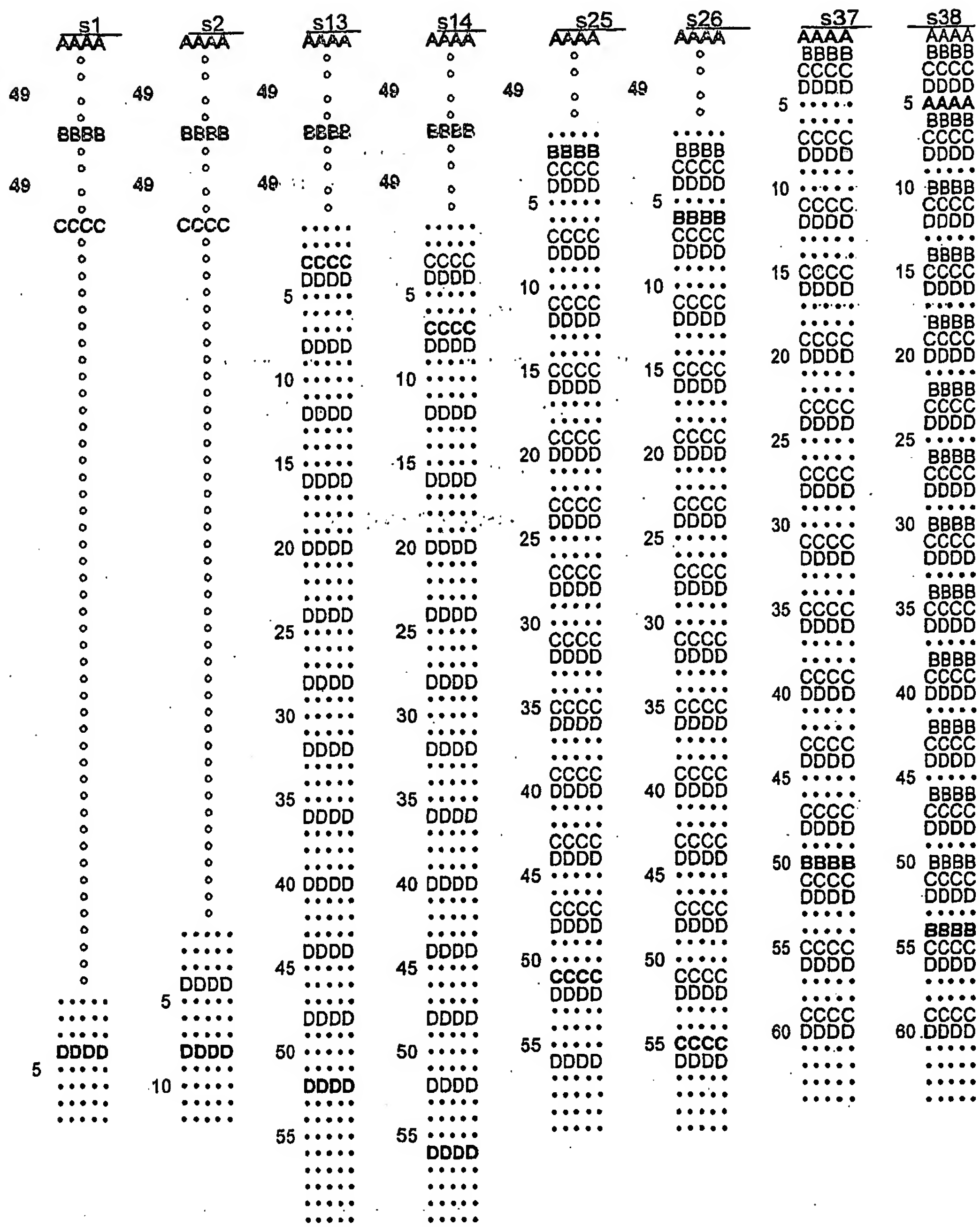


FIG. 31F



32A 32B 32C 32D 32E 32F 32G 32H

FIGs. 32A-32H

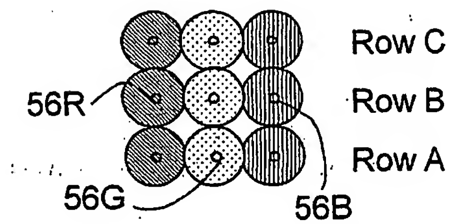


FIG. 33

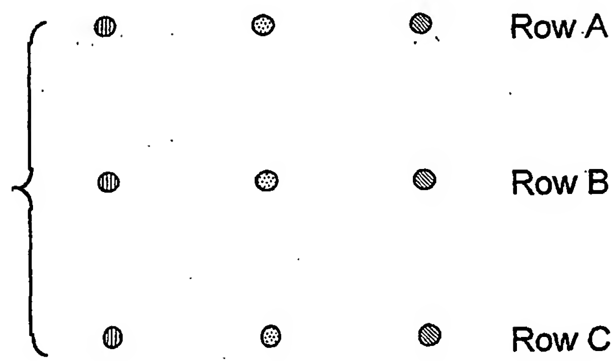
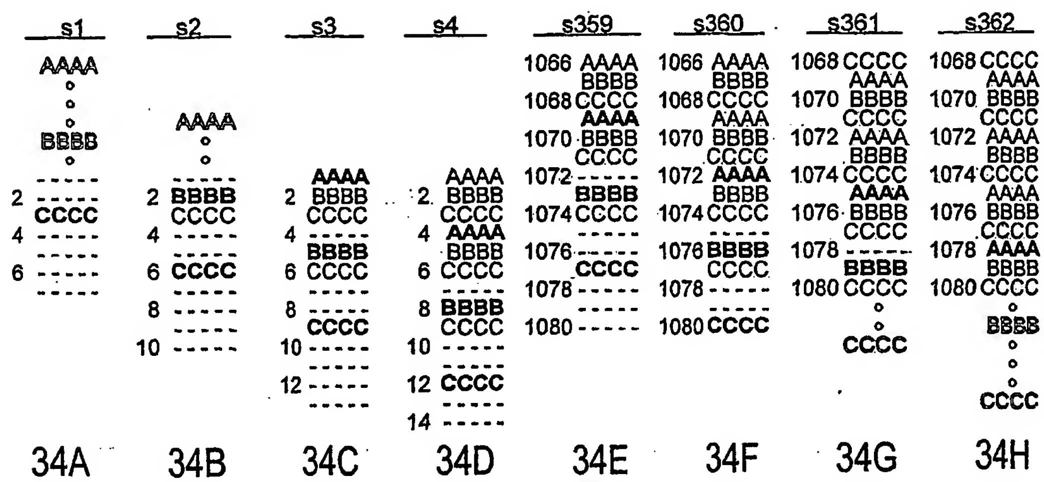


FIG. 33S



FIGs. 34A-34H

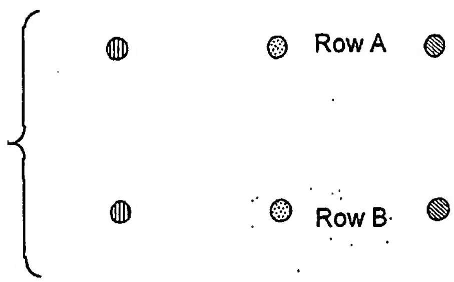


FIG. 35S

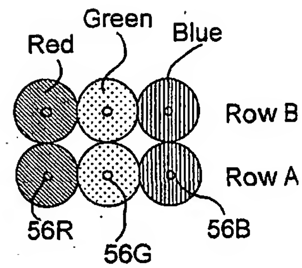
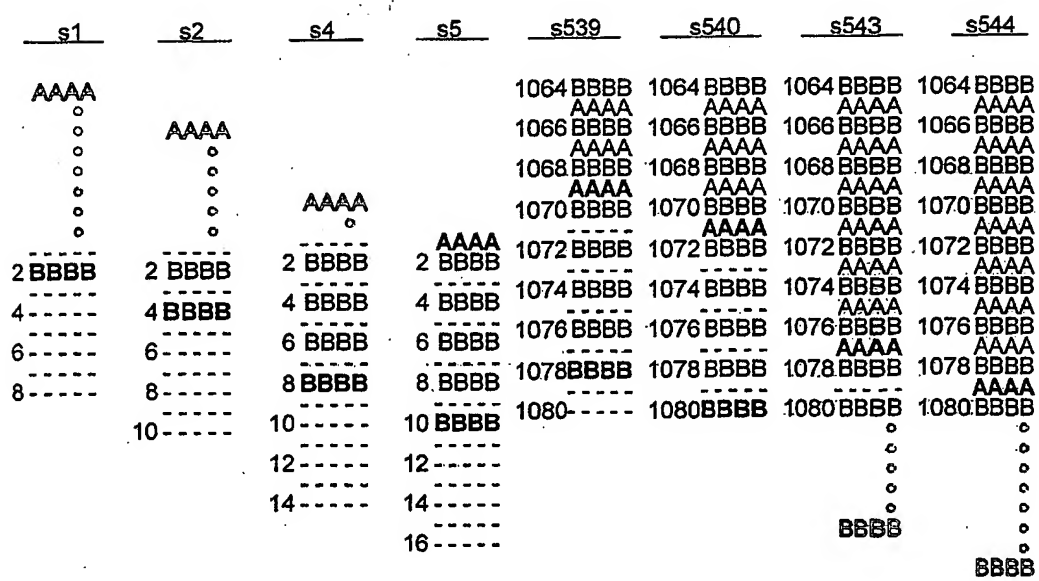
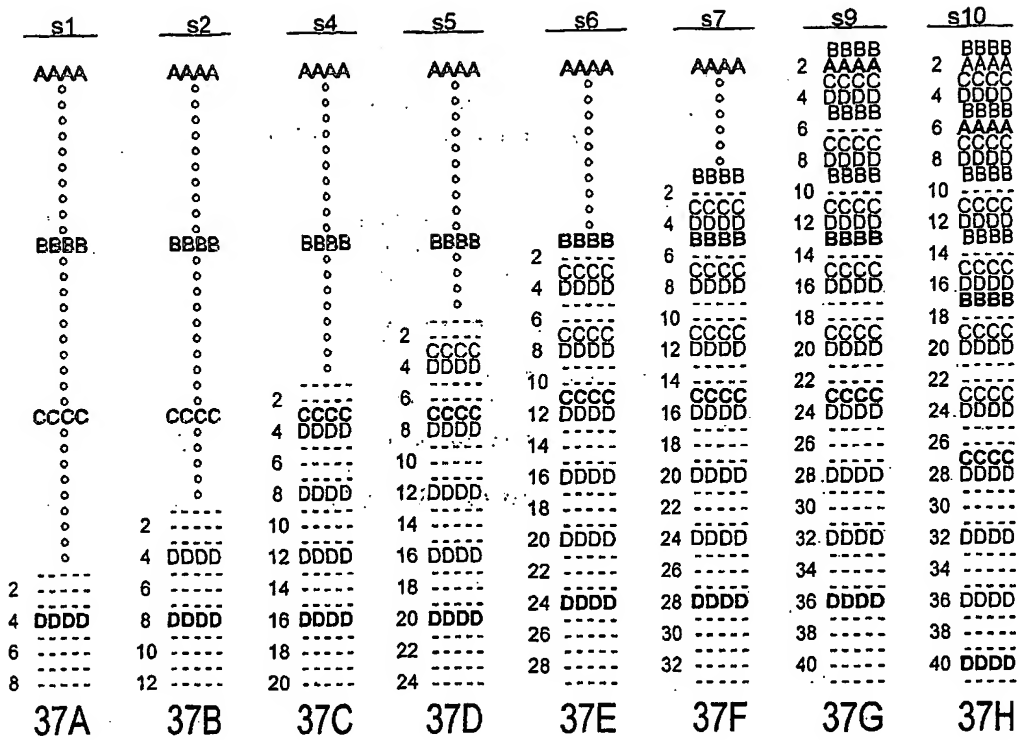


FIG. 35



36A 36B 36C 36D 36E 36F 36G 36H

FIGs.36A-36H



FIGs. 37A-37H

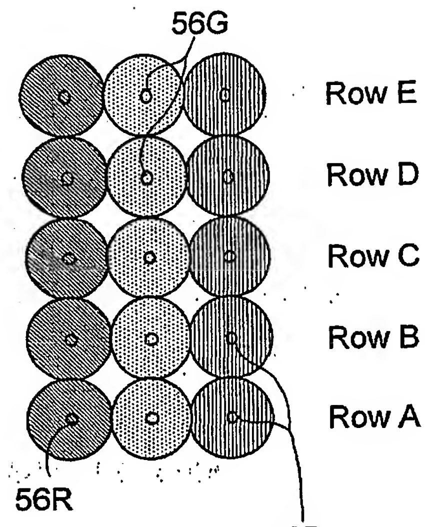


FIG. 38

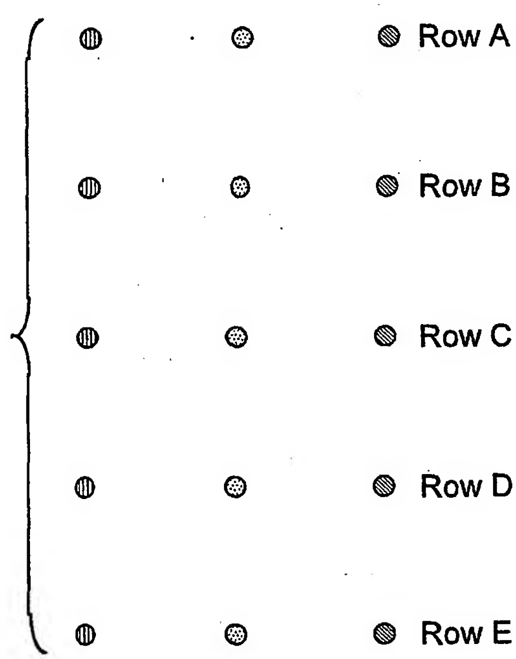
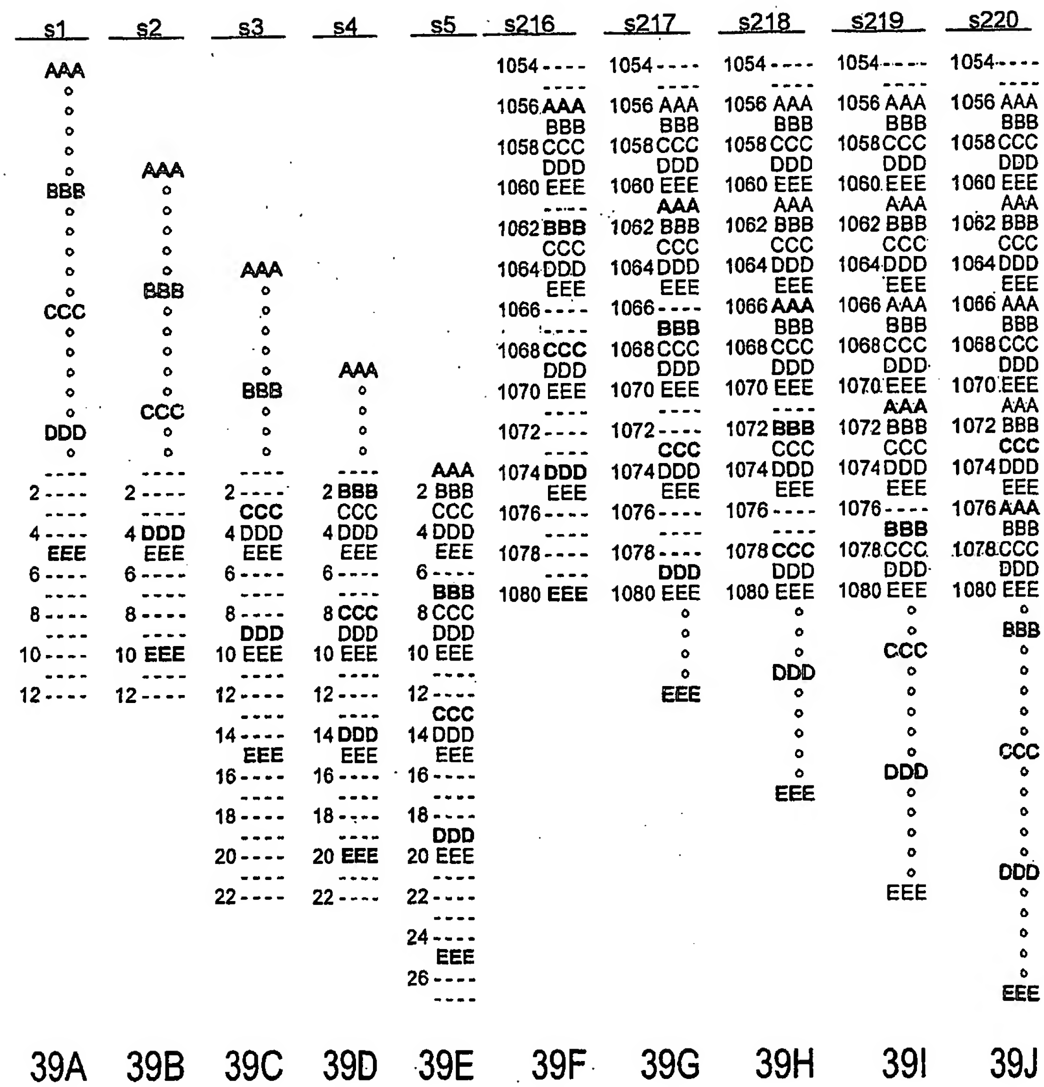


FIG. 38S


s1
s2
s3
s4
s5
s216
s217
s218
s219
s220
39A
39B
39C
39D
39E
39F
39G
39H
39I
39J

FIGs. 39A-39J

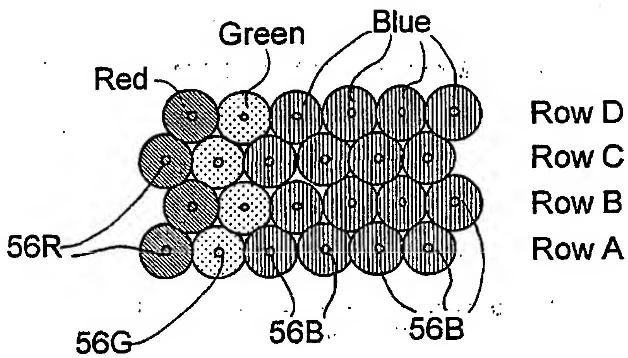


FIG. 40

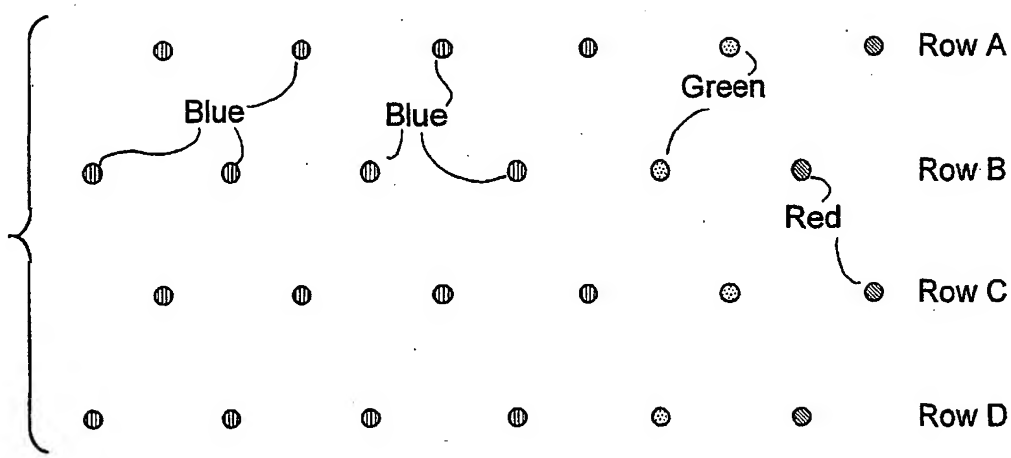
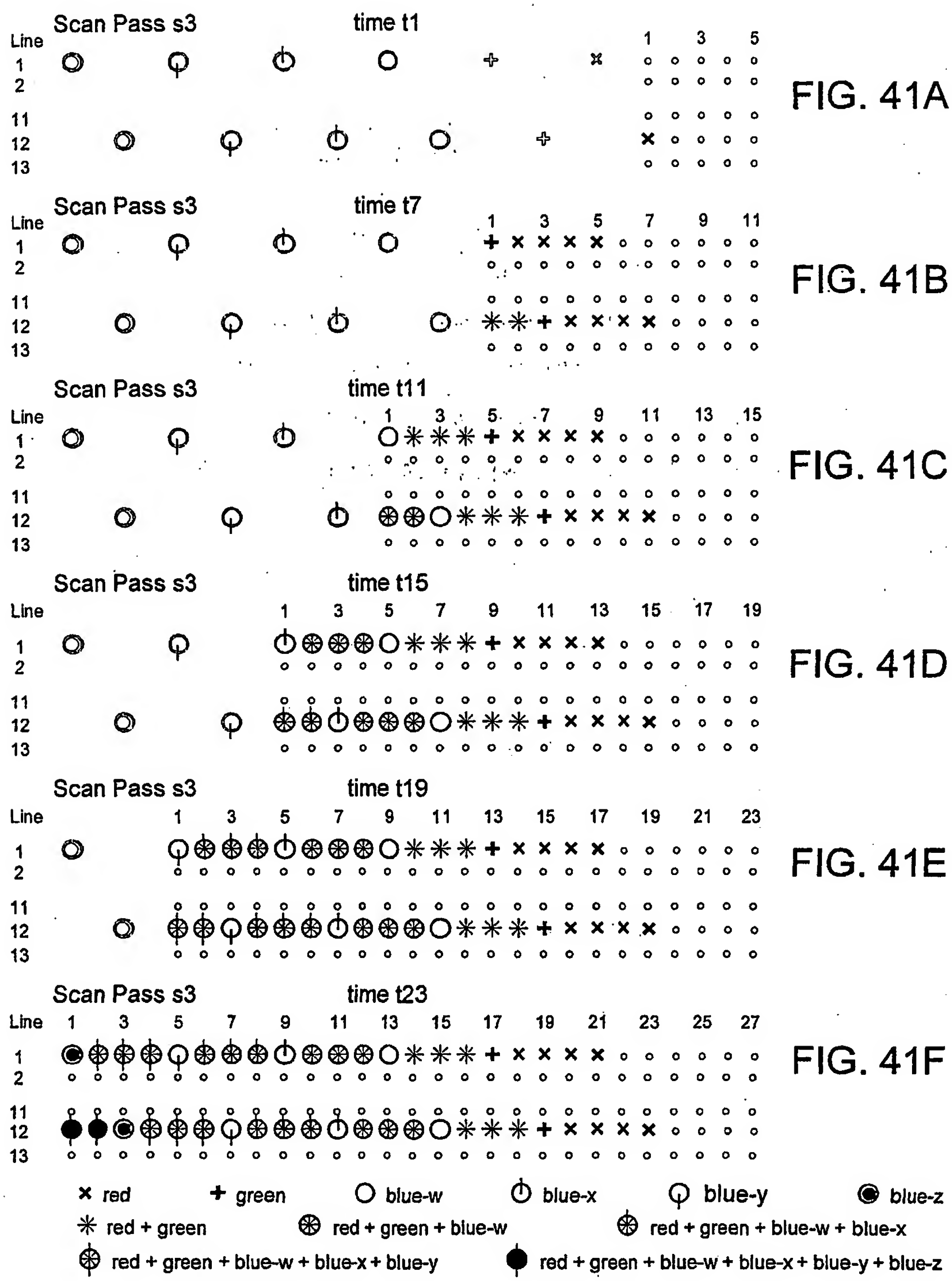


FIG. 40S


Scan Pass s3
time t1
Line
FIG. 41A
Scan Pass s3
time t7
FIG. 41B
Scan Pass s3
time t11
FIG. 41C
Scan Pass s3
time t15
FIG. 41D
Scan Pass s3
time t19
FIG. 41E
Scan Pass s3
time t23
FIG. 41F
red
green
blue-w
blue-x
blue-y
blue-z
red + green
red + green + blue-w
red + green + blue-w + blue-x
red + green + blue-w + blue-x + blue-y
red + green + blue-w + blue-x + blue-y + blue-z

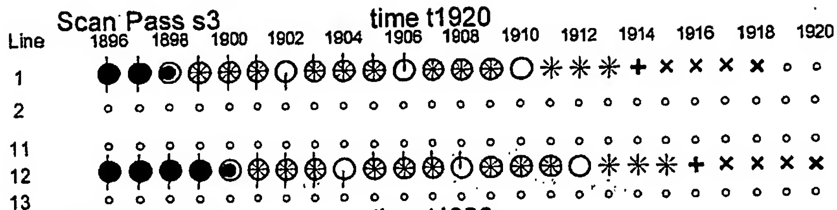


FIG.42A

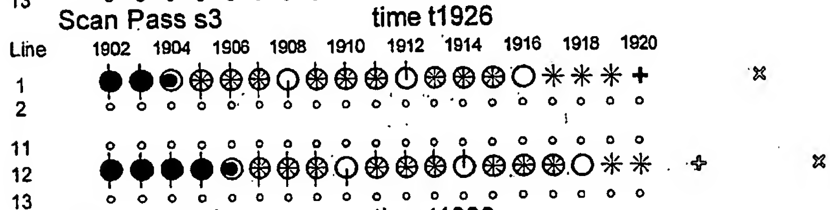


FIG.42B

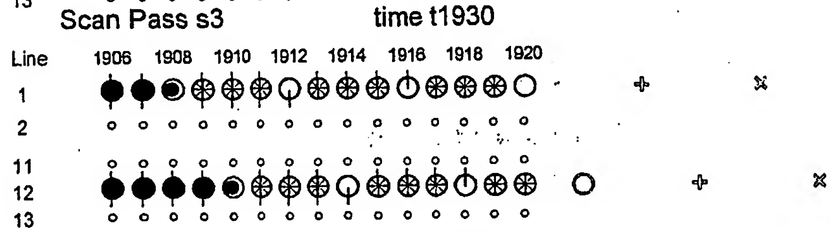


FIG.42C

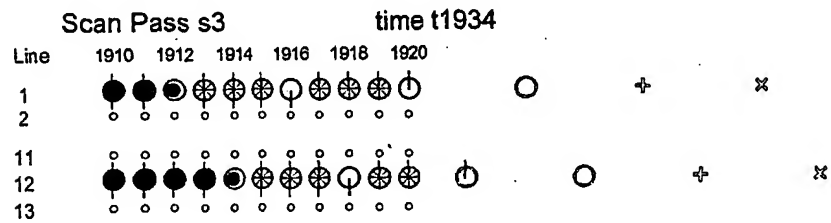


FIG.42D

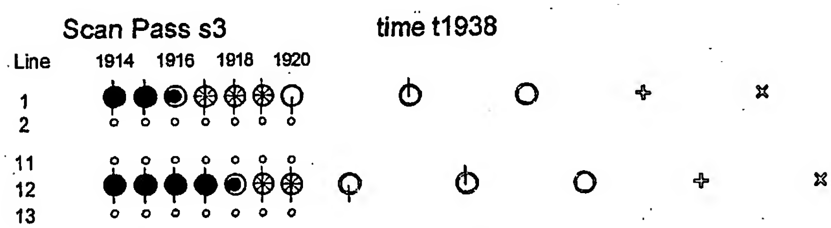


FIG.42E

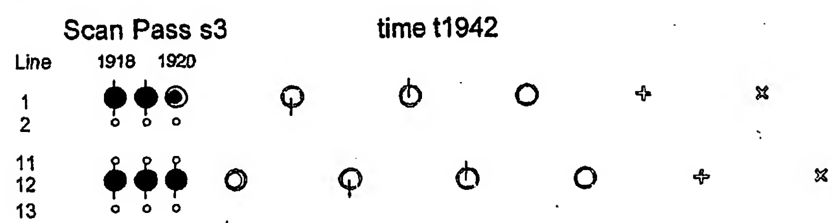


FIG. 42F

× red + green ○ blue-w blue-x blue-y blue-z

✳ red + green red + green + blue-w red + green + blue-w + blue-x

red + green + blue-w + blue-x + blue-y red + green + blue-w + blue-x + blue-y + blue-z

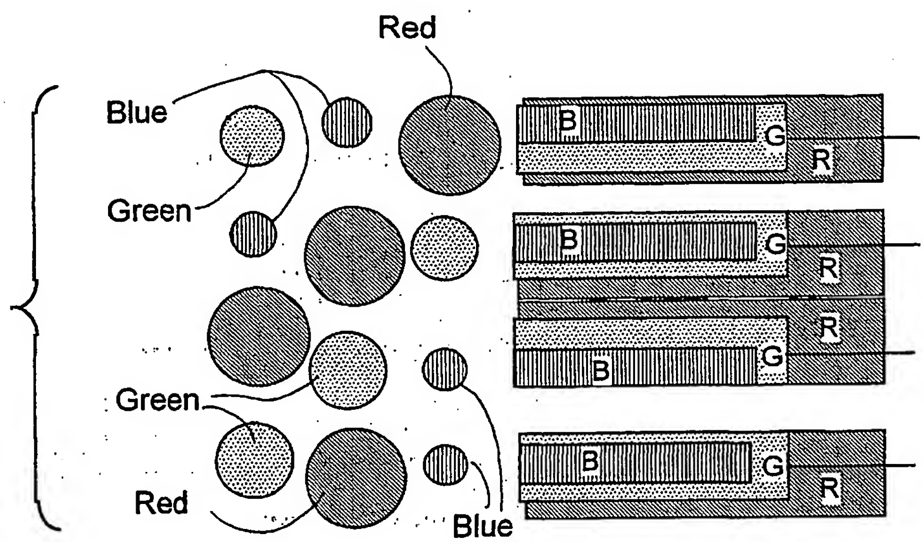

Red
Blue
Green
B
G
R
B
G
R
R
G
B
Green
Red
B
G
R
Blue

FIG. 43

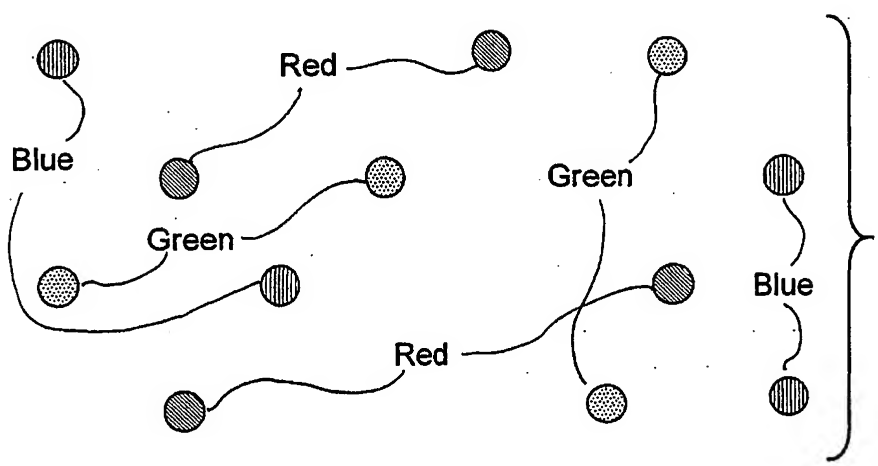

Red
Blue
Green
Green
Blue
Red

FIG. 44

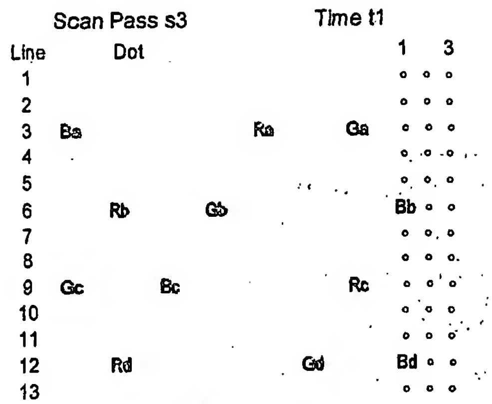


FIG. 45A

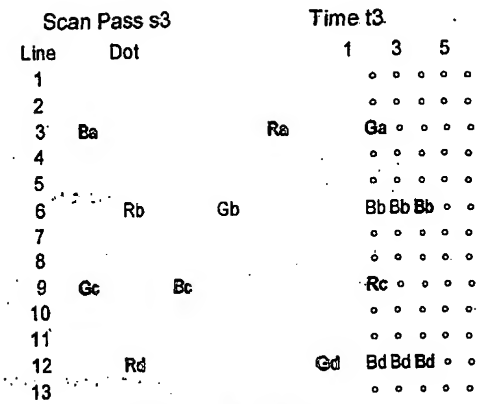


FIG. 45B

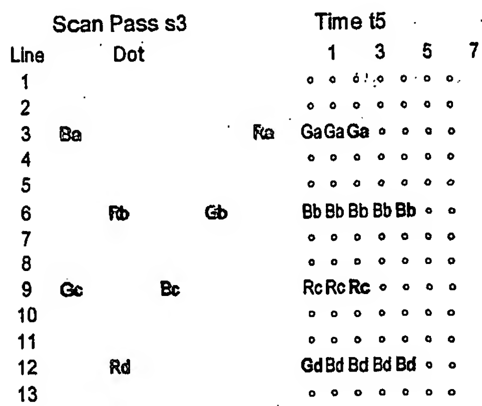


FIG. 45C

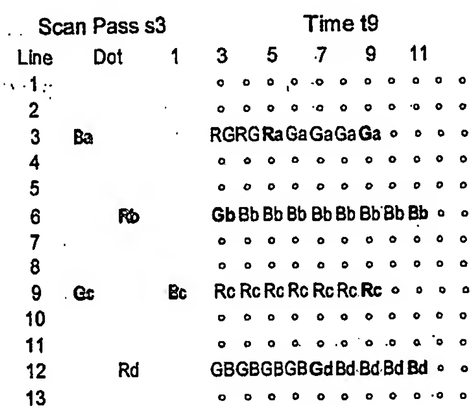


FIG. 45D

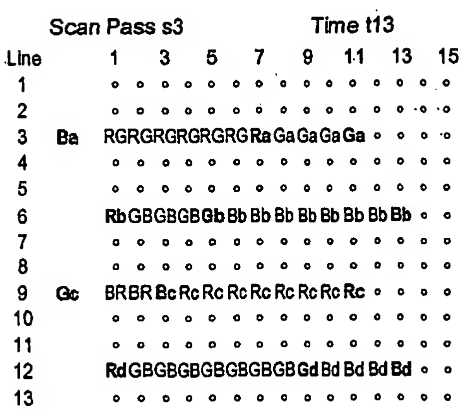


FIG. 45E

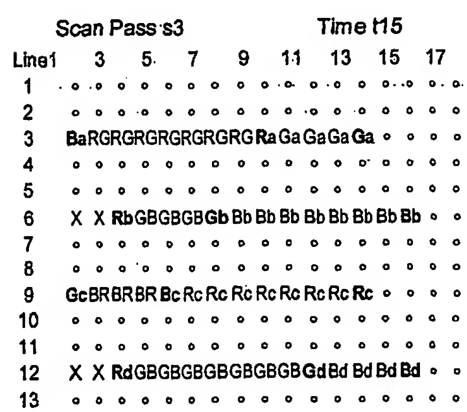


FIG. 45F

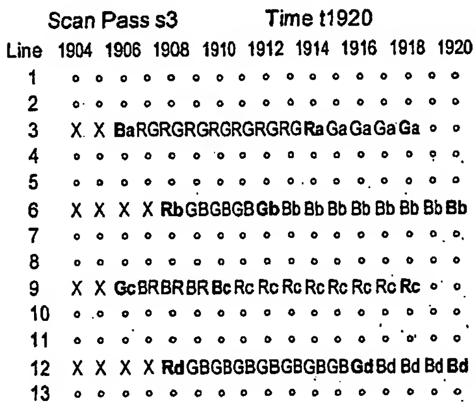


FIG. 46A

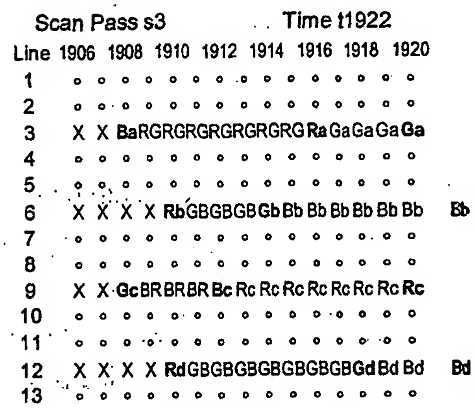


FIG. 46B

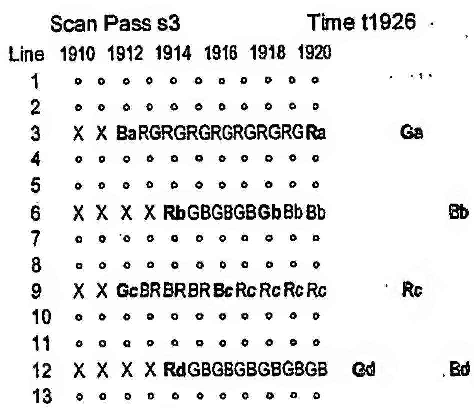


FIG. 46C

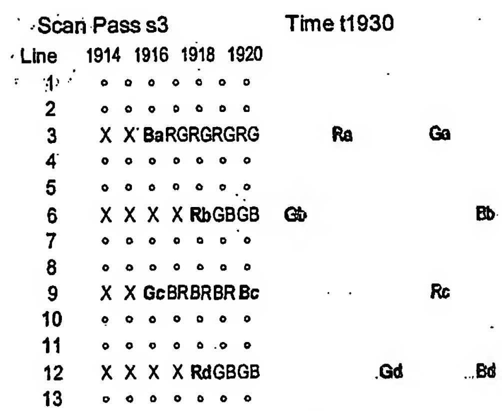


FIG. 46D

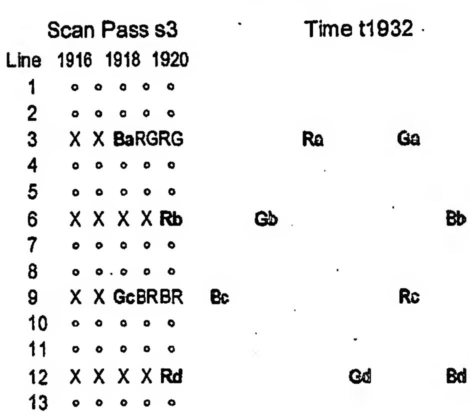


FIG. 46E

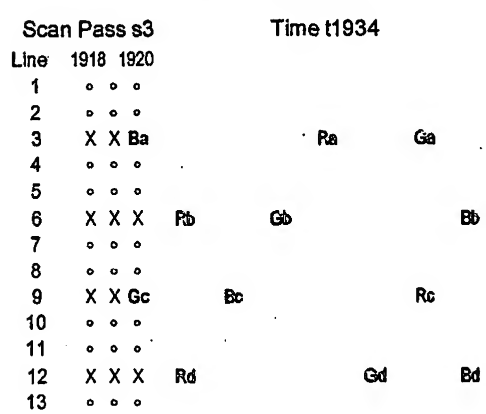


FIG. 46F

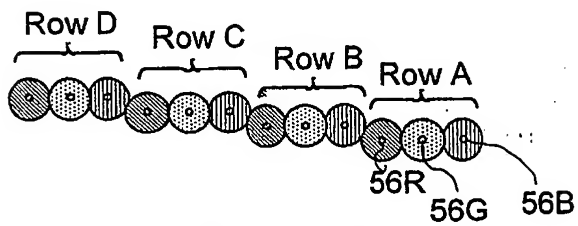


FIG. 47

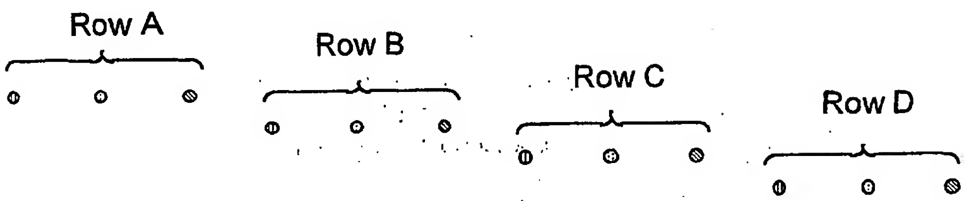


FIG. 47S

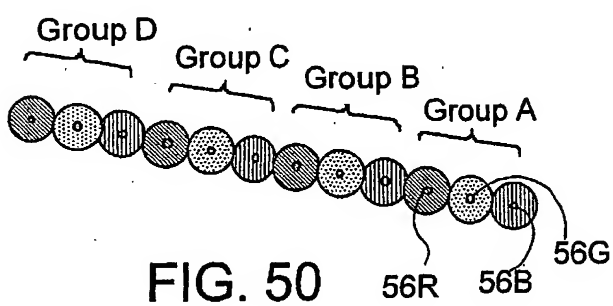


FIG. 50

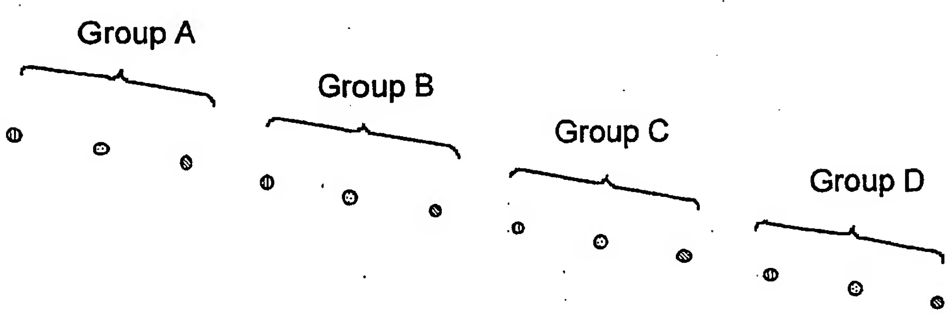


FIG. 50S

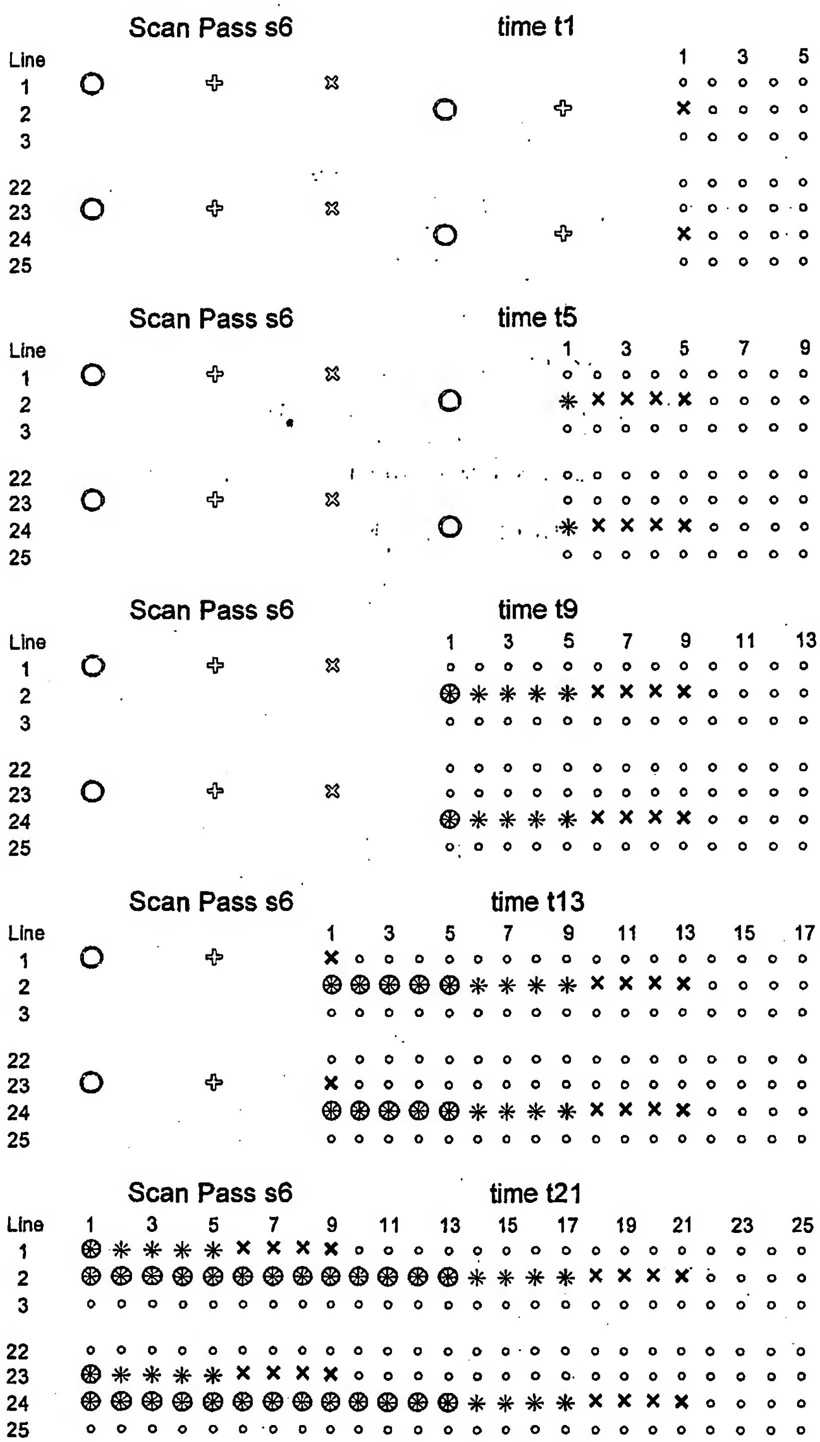


FIG. 48A

FIG. 48B

FIG. 48C

FIG. 48D

FIG. 48E

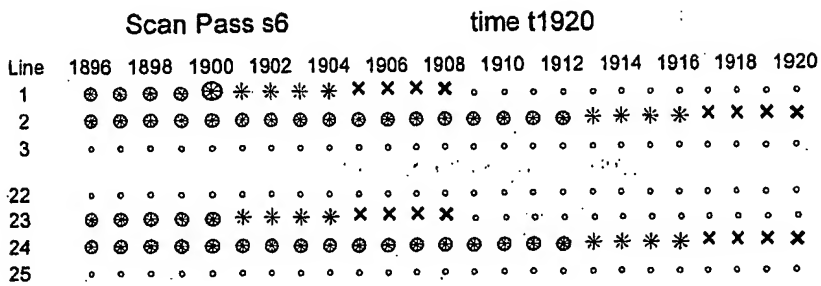


FIG. 49A

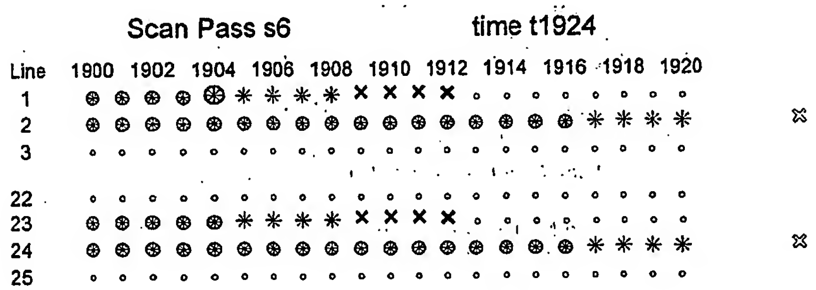


FIG. 49B

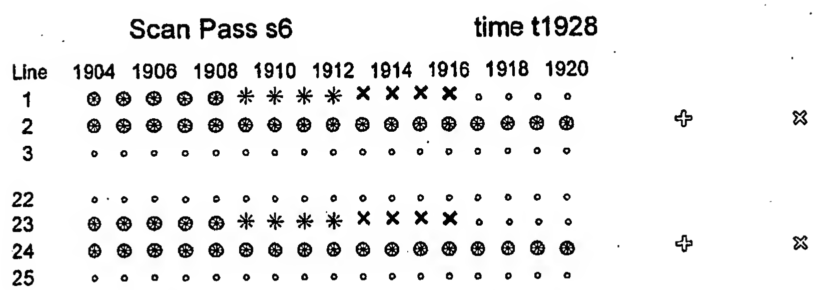


FIG. 49C

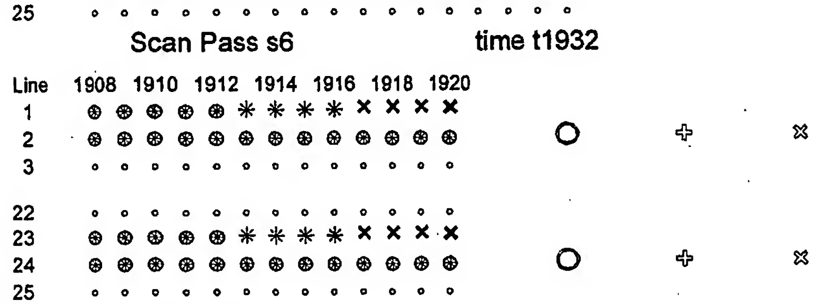


FIG. 49D

FIG. 49E

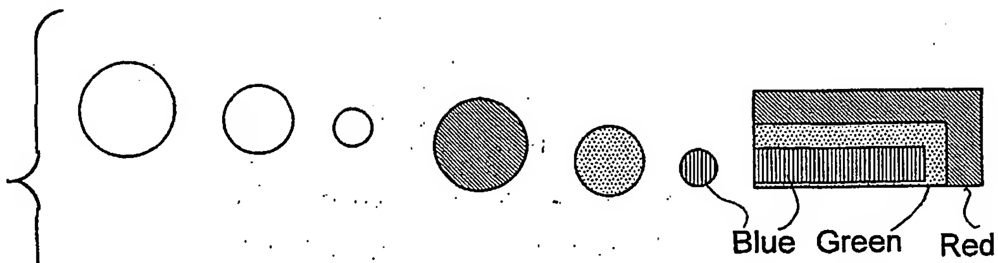


FIG. 51

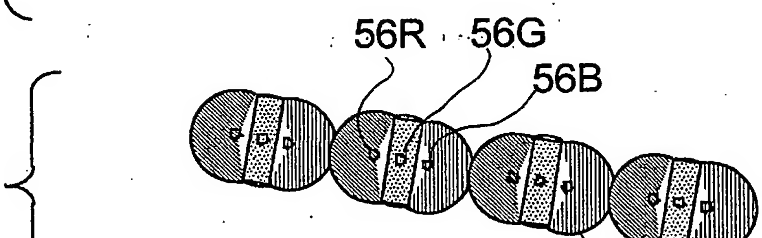


FIG. 52

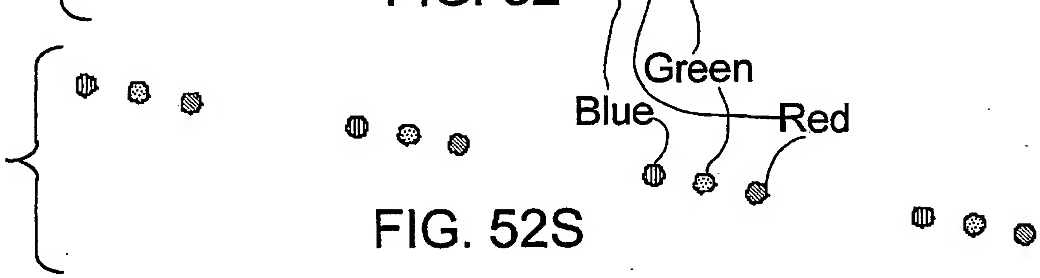


FIG. 52S

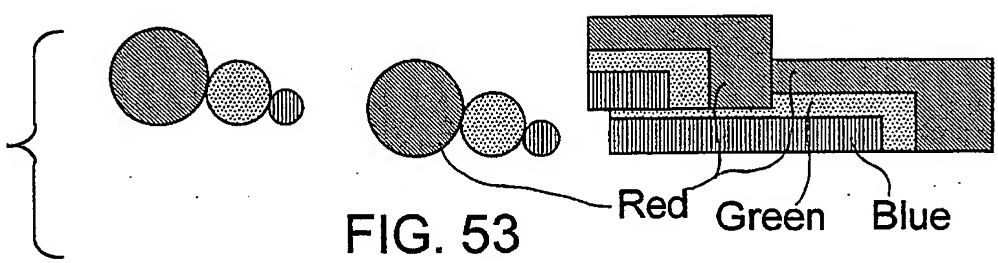


FIG. 53

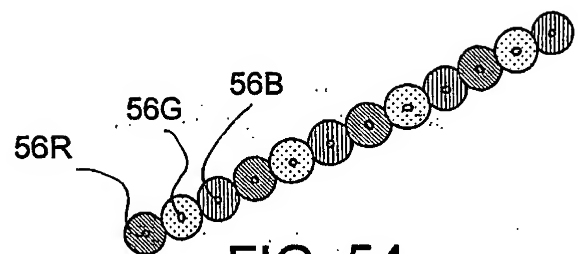


FIG. 54

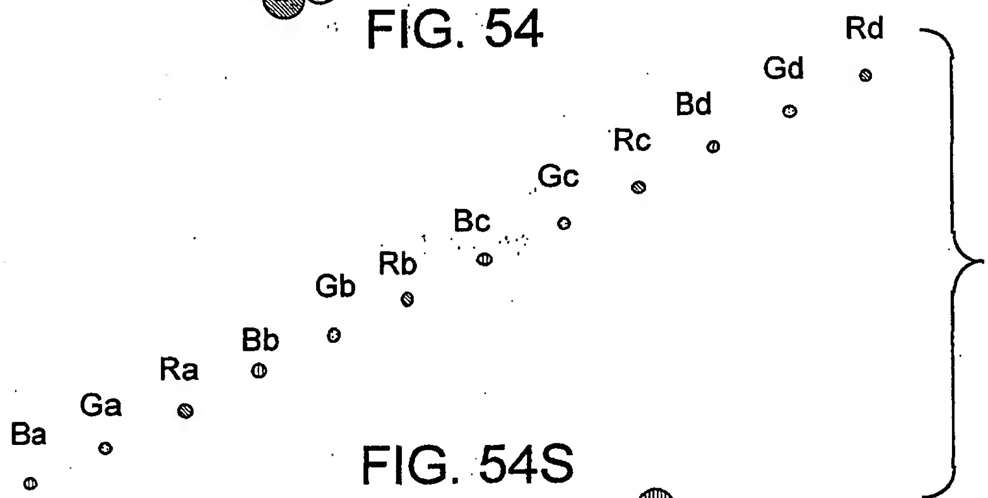


FIG. 54S

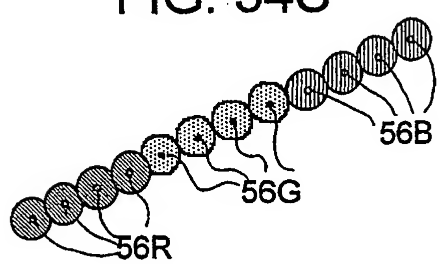


FIG. 58

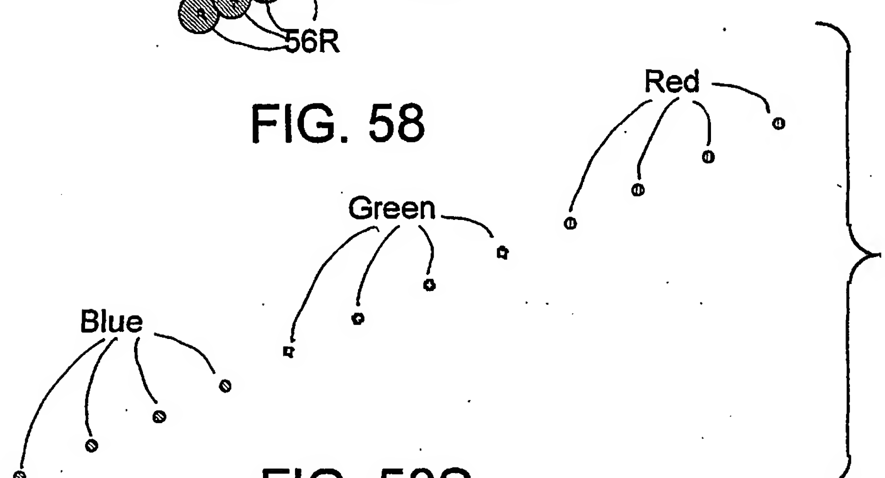
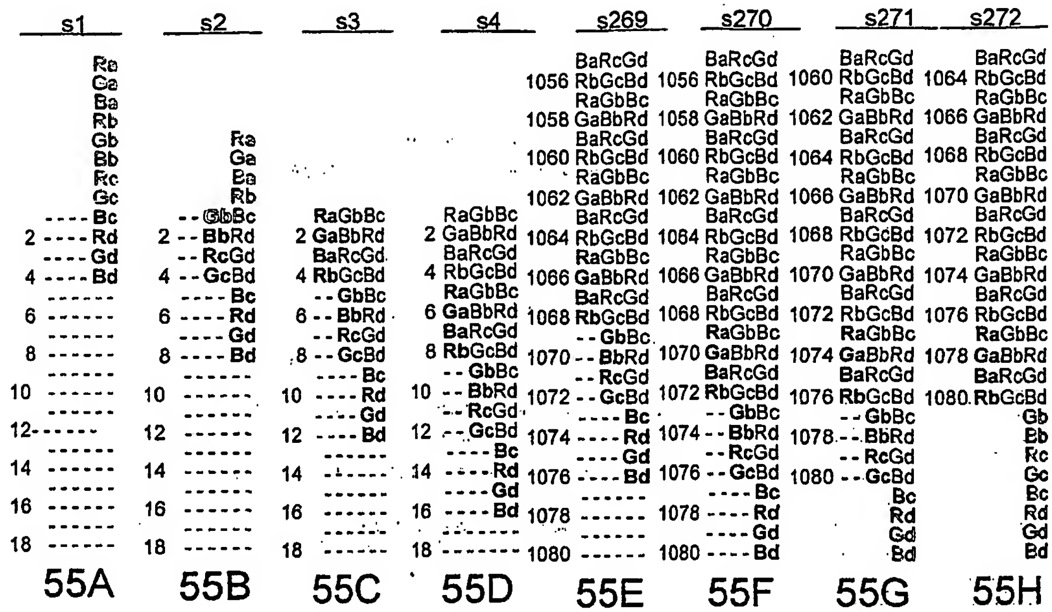
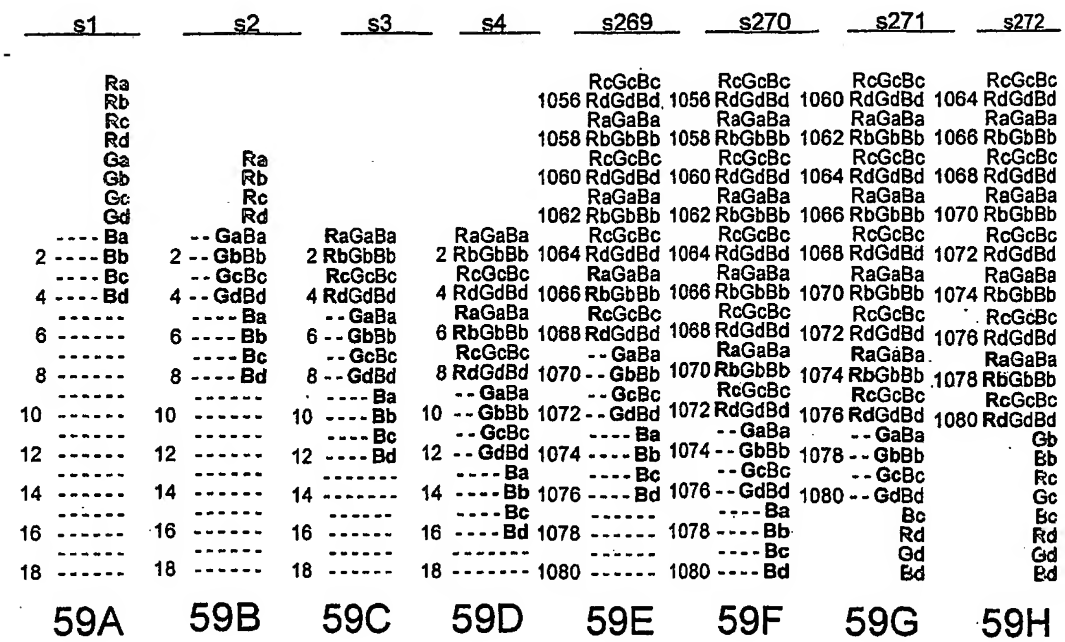


FIG. 58S



FIGs. 55A-55H



FIGs. 59A-59H

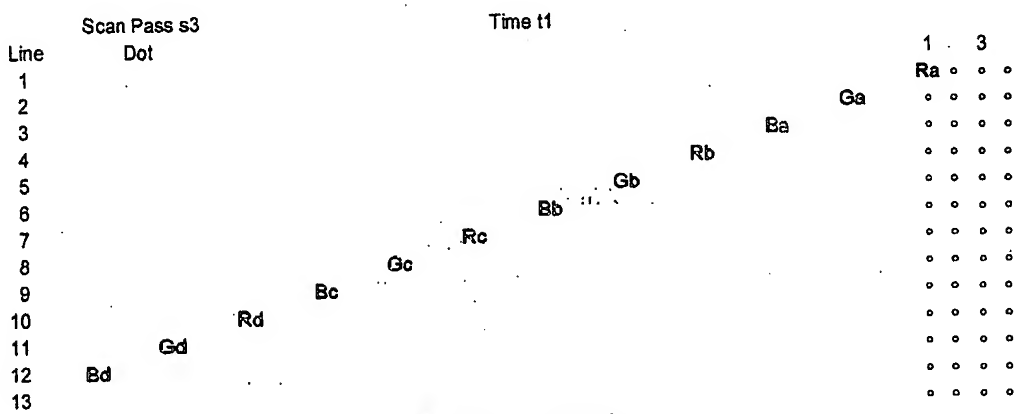


FIG. 56A

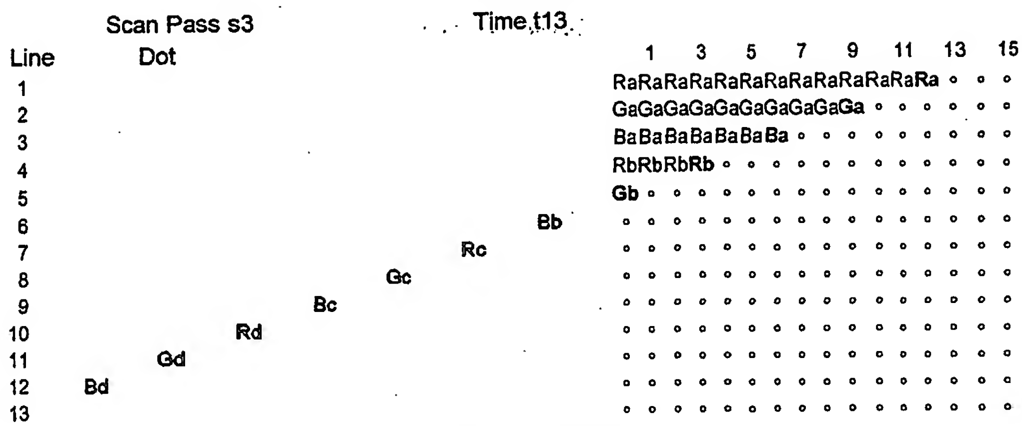


FIG. 56B

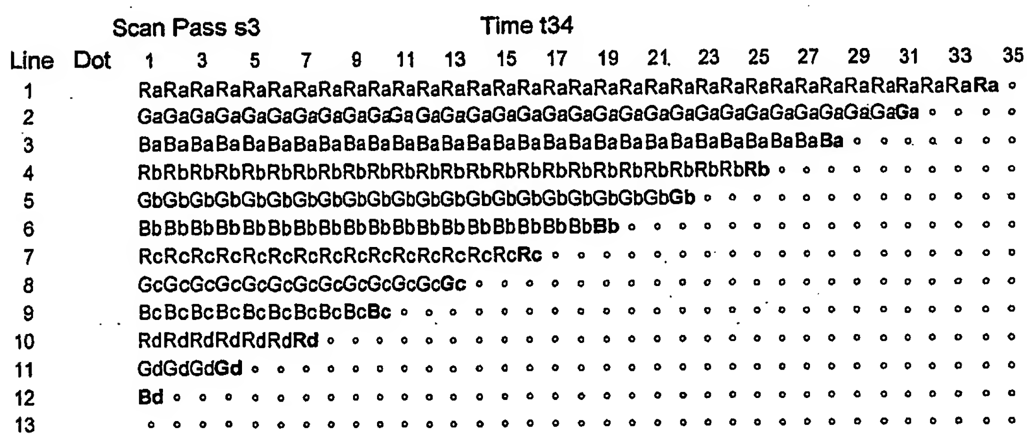


FIG. 56C

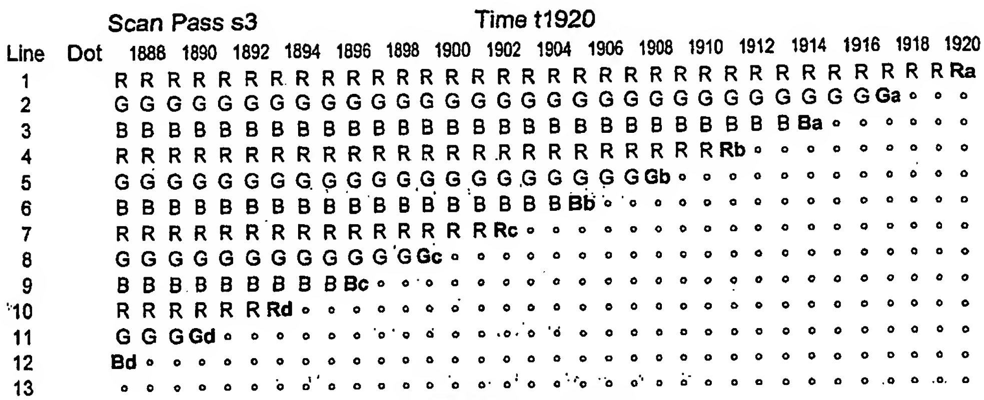


FIG. 57A

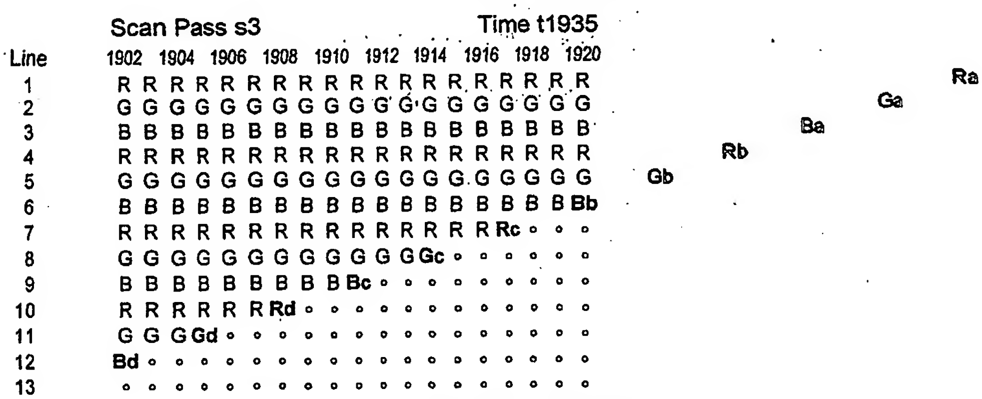


FIG. 57B

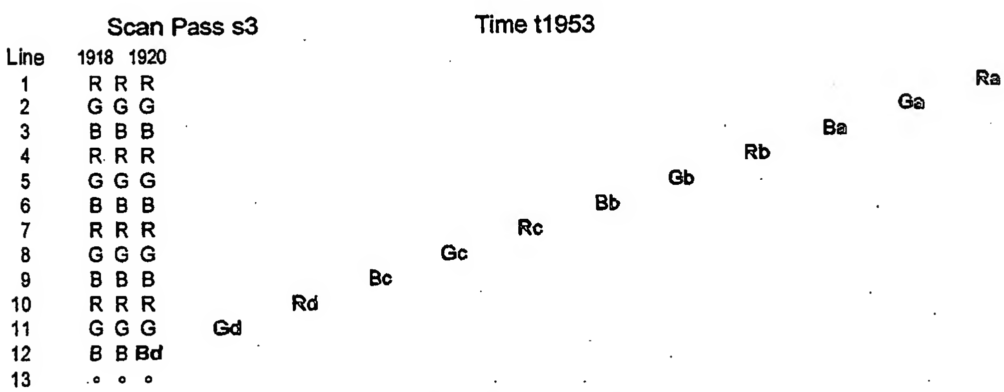


FIG. 57C

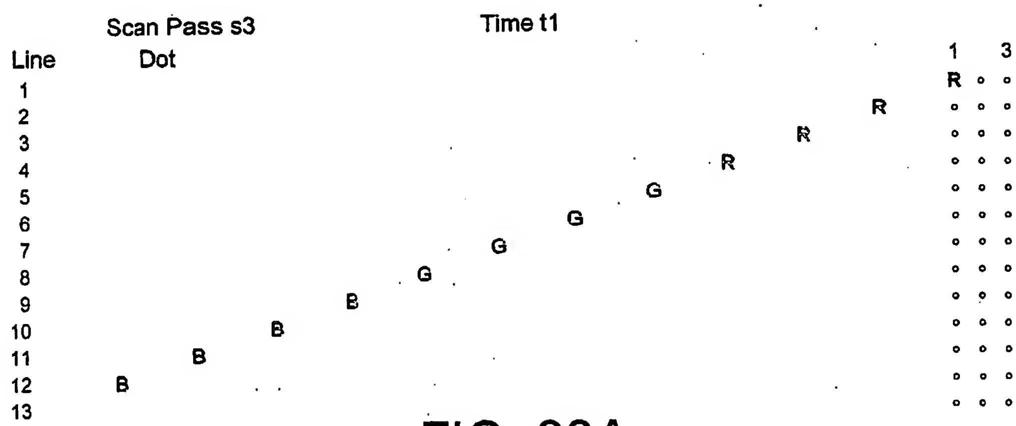


FIG. 60A

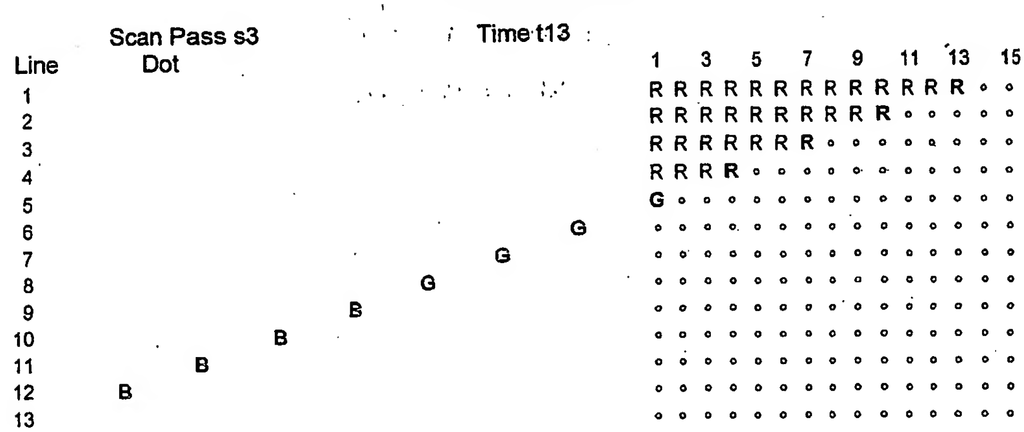


FIG. 60B

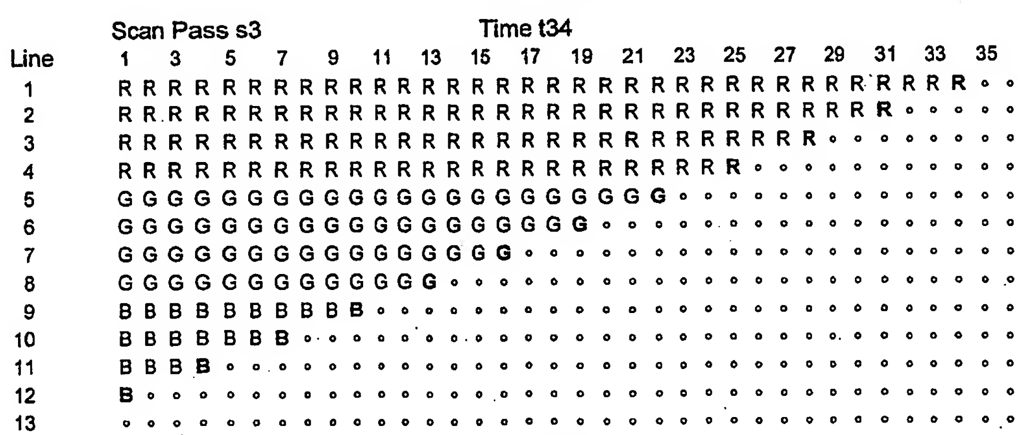


FIG. 60C

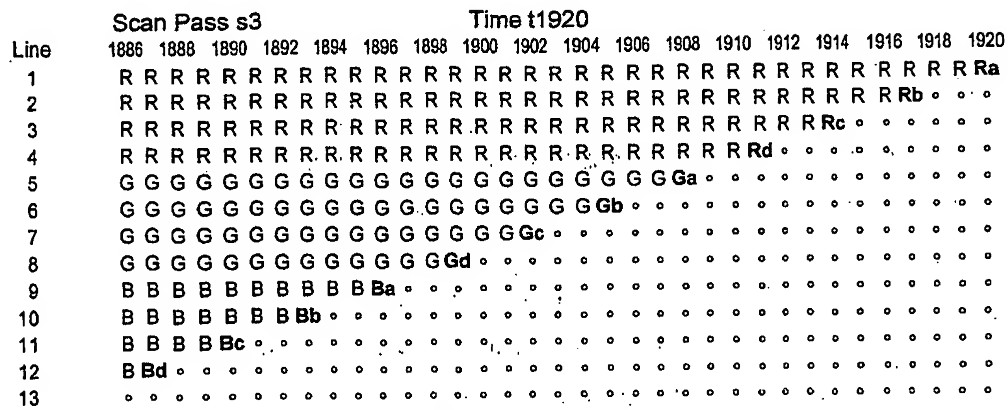


FIG. 61A

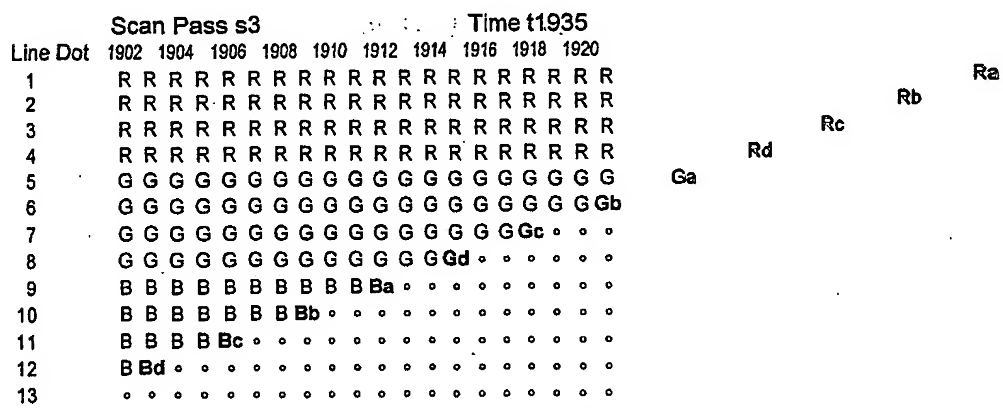


FIG. 61B

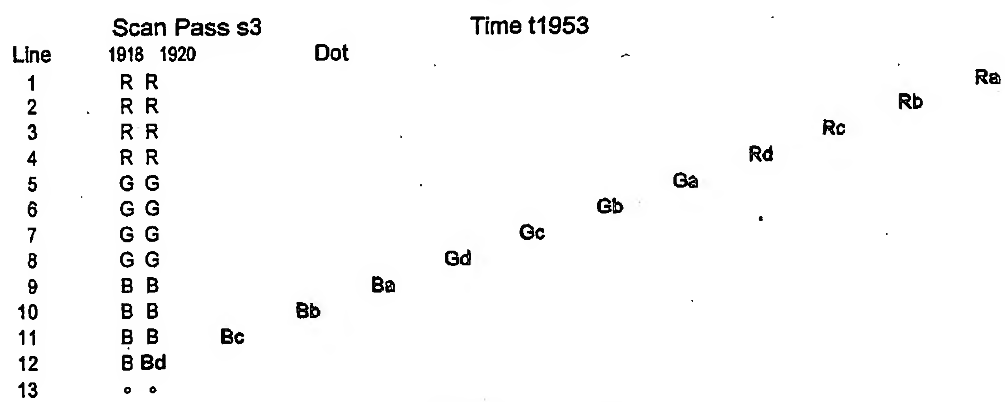


FIG. 61C

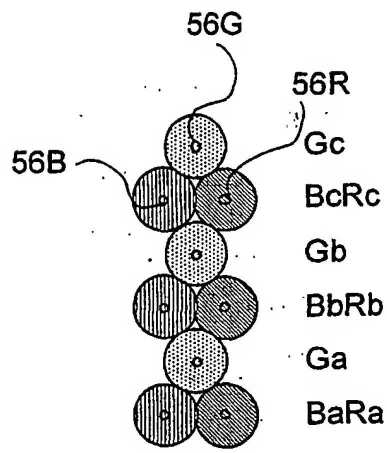


FIG. 62

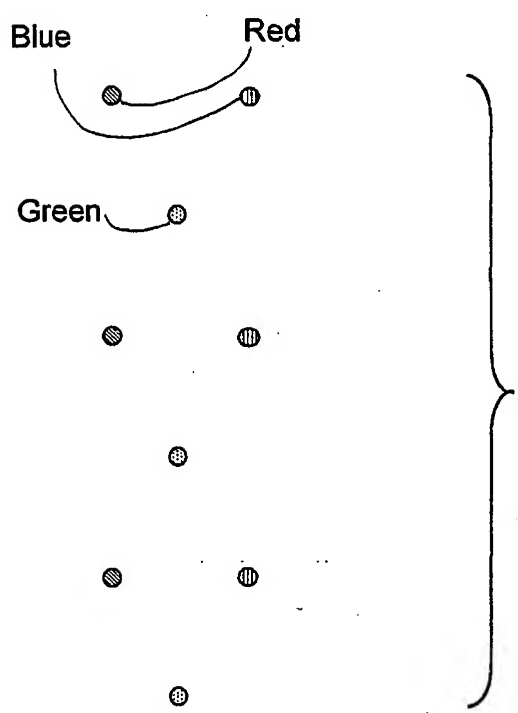
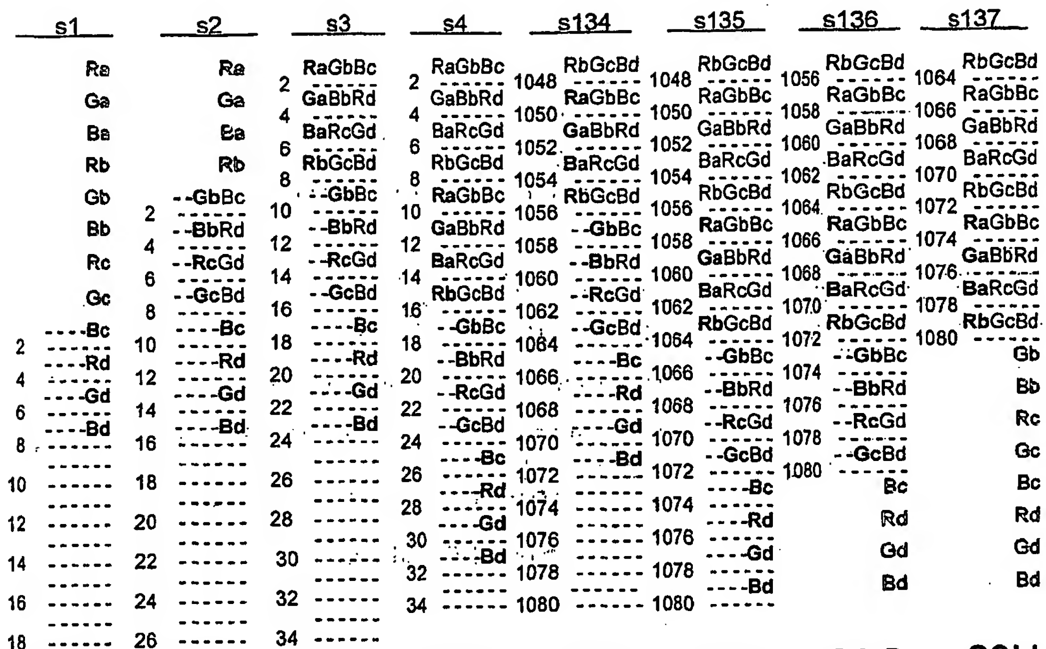
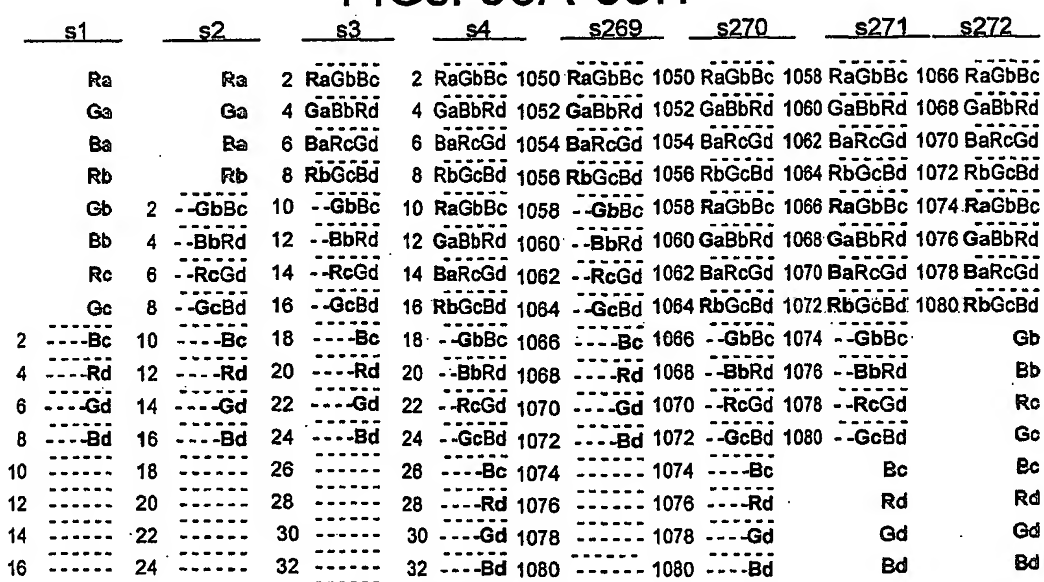


FIG. 62S



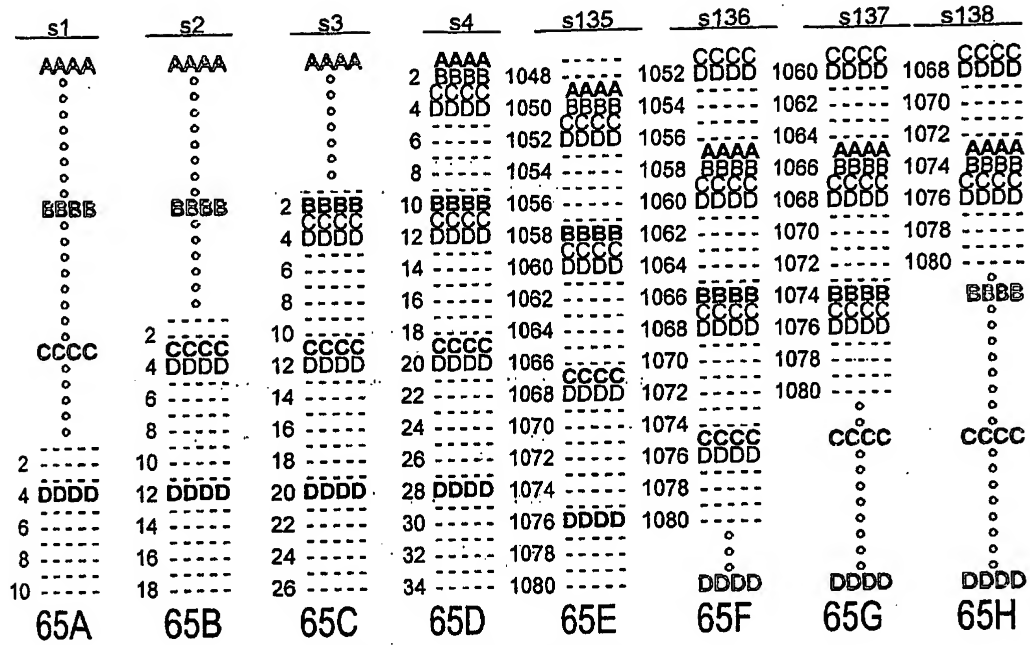
63A 63B 63C 63D 63E 63F 63G 63H

FIGs. 63A-63H

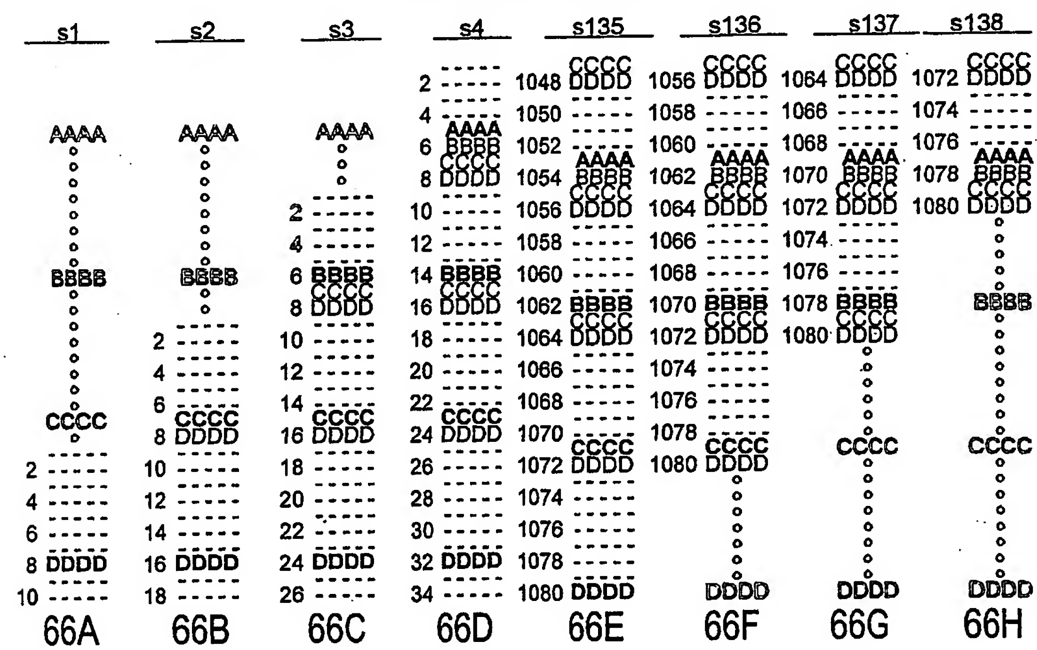


64A 64B 64C 64D 64E 64F 64G 64H

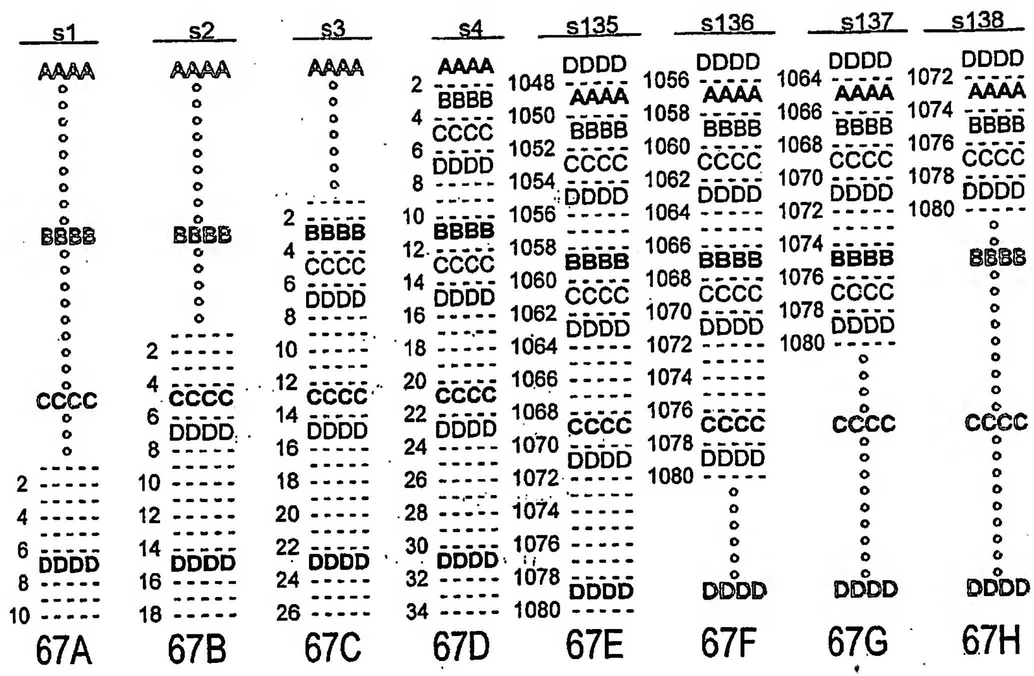
FIGs.64A-64H



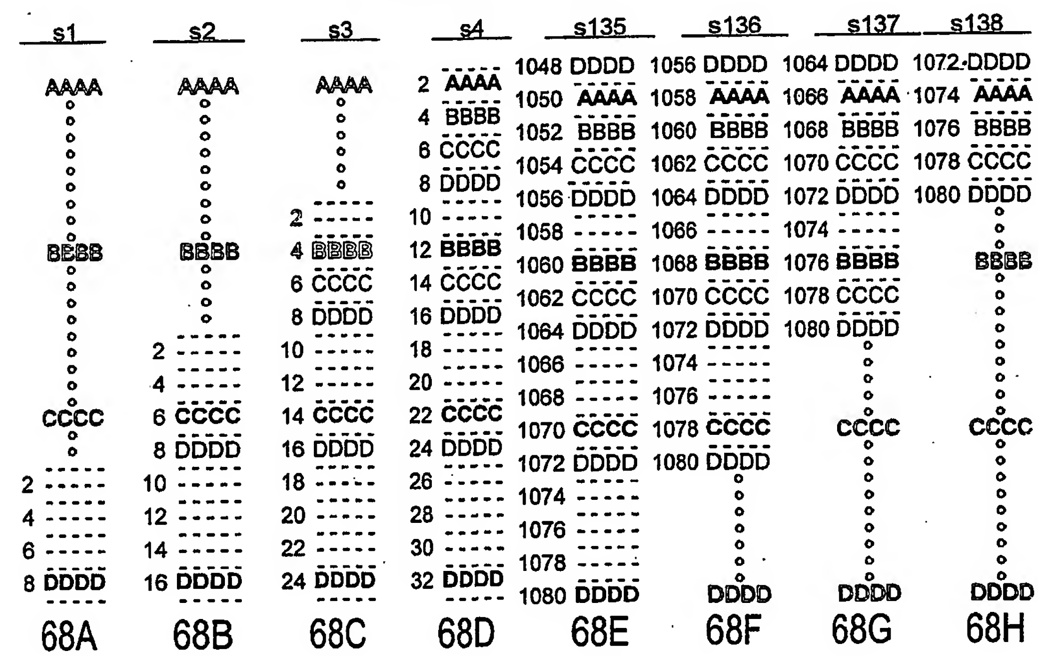
FIGs. 65A-65H



FIGs. 66A-66H



FIGs. 67A-67H



FIGs. 68A-68H

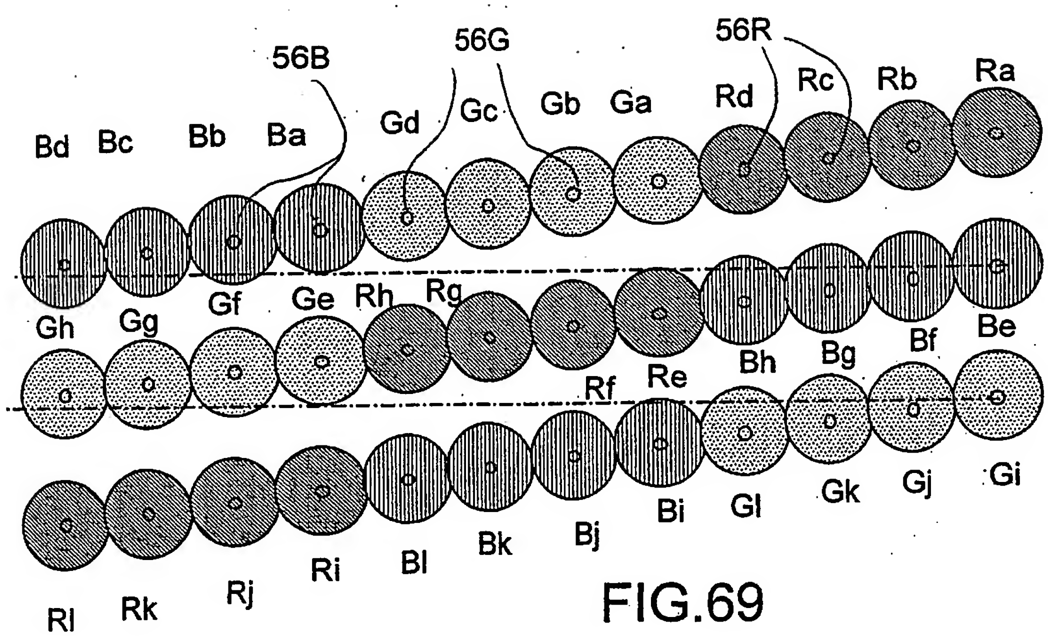

56B
56G
56R
Bd
Bc
Bb
Ba
Gd
Gc
Gb
Ga
Rd
Rc
Rb
Ra
Gh
Gg
Gf
Ge
Rh
Rg
Rf
Re
Bh
Bg
Bf
Be
Rl
Rk
Rj
Ri
Bl
Bk
Bj
Bi
Gl
Gk
Gj
Gi

FIG.69

70A — s1

```
      Rl
      Rk
      Rj
      Ri
      Bl
      Bk
      Bj
      Bi
      Gl
      Gk
      Gj
      Gi
      Gh
      Gg
      Gf
      Ge
      Rh
      Rg
      Rf
      Re
      Bh
      Bg
      Bf
      Be
   ----Bd
 2 ----Bc
   ----Bb
 4 ----Ba
   ----Gd
 6 ----Gc
   ----Gb
 8 ----Ga
   ----Rd
10 ----Rc
   ----Rb
12 ----Ra
   ------
14 ------
   ------
16 ------
   ------
18 ------
   ------
20 ------
   ------
22 ------
   ------
24 ------
   ------
26 ------
   ------
28 ------
```

70B — s2

```
         Rl
         Rk
         Rj
         Ri
         Bl
         Bk
         Bj
         Bi
         Gl
         Gk
         Gj
         Gi
   --GhBd
 2 --GgBc
   --GfBb
 4 --GeBa
   --RhGd
 6 --RgGc
   --RfGb
 8 --ReGa
   --BhRd
10 --BgRc
   --BfRb
12 --BeRa
   ----Bd
14 ----Bc
   ----Bb
16 ----Ba
   ----Gd
18 ----Gc
   ----Gb
20 ----Ga
   ----Rd
22 ----Rc
   ----Rb
24 ----Ra
   ------
26 ------
   ------
28 ------
   ------
30 ------
   ------
32 ------
   ------
34 ------
   ------
36 ------
   ------
38 ------
   ------
40 ------
```

70C — s3

```
   RlGhBd
 2 RkGgBc
   RjGfBb
 4 RiGeBa
   BlRhGd
 6 BkRgGc
   BjRfGb
 8 BiReGa
   GlBhRd
10 GkBgRc
   GjBfRb
12 GiBeRa
   --GhBd
14 --GgBc
   --GfBb
16 --GeBa
   --RhGd
18 --RgGc
   --RfGb
20 --ReGa
   --BhRd
22 --BgRc
   --BfRb
24 --BeRa
   ----Bd
26 ----Bc
   ----Bb
28 ----Ba
   ----Gd
30 ----Gc
   ----Gb
32 ----Ga
   ----Rd
34 ----Rc
   ----Rb
36 ----Ra
   ------
38 ------
   ------
40 ------
   ------
42 ------
   ------
44 ------
   ------
46 ------
   ------
48 ------
   ------
50 ------
   ------
52 ------
```

70D — s4

```
   RlGhBd
 2 RkGgBc
   RjGfBb
 4 RiGeBa
   BlRhGd
 6 BkRgGc
   BjRfGb
 8 BiReGa
   GlBhRd
10 GkBgRc
   GjBfRb
12 GiBeRa
   RlGhBd
14 RkGgBc
   RjGfBb
16 RiGeBa
   BlRhGd
18 BkRgGc
   BjRfGb
20 BiReGa
   GlBhRd
22 GkBgRc
   GjBfRb
24 GiBeRa
   --GhBd
26 --GgBc
   --GfBb
28 --GeBa
   --RhGd
30 --RgGc
   --RfGb
32 --ReGa
   --BhRd
34 --BgRc
   --BfRb
36 --BeRa
   ----Bd
38 ----Bc
   ----Bb
40 ----Ba
   ----Gd
42 ----Gc
   ----Gb
44 ----Ga
   ----Rd
46 ----Rc
   ----Rb
48 ----Ra
   ------
50 ------
   ------
52 ------
```

70E — s269

```
     GlBhRd
1030 GkBgRc
     GjBfRb
1032 GiBeRa
     RlGhBd
1034 RkGgBc
     RjGfBb
1036 RiGeBa
     BlRhGd
1038 BkRgGc
     BjRfGb
1040 BiReGa
     GlBhRd
1042 GkBgRc
     GjBfRb
1044 GiBeRa
     --GhBd
1046 --GgBc
     --GfBb
1048 --GeBa
     --RhGd
1050 --RgGc
     --RfGb
1052 --ReGa
     --BhRd
1054 --BgRc
     --BfRb
1056 --BeRa
     ----Bd
1058 ----Bc
     ----Bb
1060 ----Ba
     ----Gd
1062 ----Gc
     ----Gb
1064 ----Ga
     ----Rd
1066 ----Rc
     ----Rb
1068 ----Ra
     ------
1070 ------
     ------
1072 ------
     ------
1074 ------
     ------
1076 ------
     ------
1078 ------
     ------
1080 ------
```

70F — s270

```
     GlBhRd
1030 GkBgRc
     GjBfRb
1032 GiBeRa
     RlGhBd
1034 RkGgBc
     RjGfBb
1036 RiGeBa
     BlRhGd
1038 BkRgGc
     BjRfGb
1040 BiReGa
     GlBhRd
1042 GkBgRc
     GjBfRb
1044 GiBeRa
     RlGhBd
1046 RkGgBc
     RjGfBb
1048 RiGeBa
     BlRhGd
1050 BkRgGc
     BjRfGb
1052 BiReGa
     GlBhRd
1054 GkBgRc
     GjBfRb
1056 GiBeRa
     --GhBd
1058 --GgBc
     --GfBb
1060 --GeBa
     --RhGd
1062 --RgGc
     --RfGb
1064 --ReGa
     --BhRd
1066 --BgRc
     --BfRb
1068 --BeRa
     ----Bd
1070 ----Bc
     ----Bb
1072 ----Ba
     ----Gd
1074 ----Gc
     ----Gb
1076 ----Ga
     ----Rd
1078 ----Rc
     ----Rb
1080 ----Ra
```

70G — s271

```
     GlBhRd
1042 GkBgRc
     GjBfRb
1044 GiBeRa
     RlGhBd
1046 RkGgBc
     RjGfBb
1048 RiGeBa
     BlRhGd
1050 BkRgGc
     BjRfGb
1052 BiReGa
     GlBhRd
1054 GkBgRc
     GjBfRb
1056 GiBeRa
     RlGhBd
1058 RkGgBc
     RjGfBb
1060 RiGeBa
     BlRhGd
1062 BkRgGc
     BjRfGb
1064 BiReGa
     GlBhRd
1066 GkBgRc
     GjBfRb
1068 GiBeRa
     --GhBd
1070 --GgBc
     --GfBb
1072 --GeBa
     --RhGd
1074 --RgGc
     --RfGb
1076 --ReGa
     --BhRd
1078 --BgRc
     --BfRb
1080 --BeRa
         Bd
         Bc
         Bb
         Ba
         Gd
         Gc
         Gb
         Ga
         Rd
         Rc
         Rb
         Ra
```

70H — s272

```
     GlBhRd
1054 GkBgRc
     GjBfRb
1056 GiBeRa
     RlGhBd
1058 RkGgBc
     RjGfBb
1060 RiGeBa
     BlRhGd
1062 BkRgGc
     BjRfGb
1064 BiReGa
     GlBhRd
1066 GkBgRc
     GjBfRb
1068 GiBeRa
     RlGhBd
1070 RkGgBc
     RjGfBb
1072 RiGeBa
     BlRhGd
1074 BkRgGc
     BjRfGb
1076 BiReGa
     GlBhRd
1078 GkBgRc
     GjBfRb
1080 GiBeRa
         Gh
         Gg
         Gf
         Ge
         Rh
         Rg
         Rf
         Re
         Bh
         Bg
         Bf
         Be
         Bd
         Bc
         Bb
         Ba
         Gd
         Gc
         Gb
         Ga
         Rd
         Rc
         Rb
         Ra
```

FIGs. 70A-70H

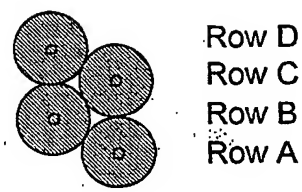


FIG. 71

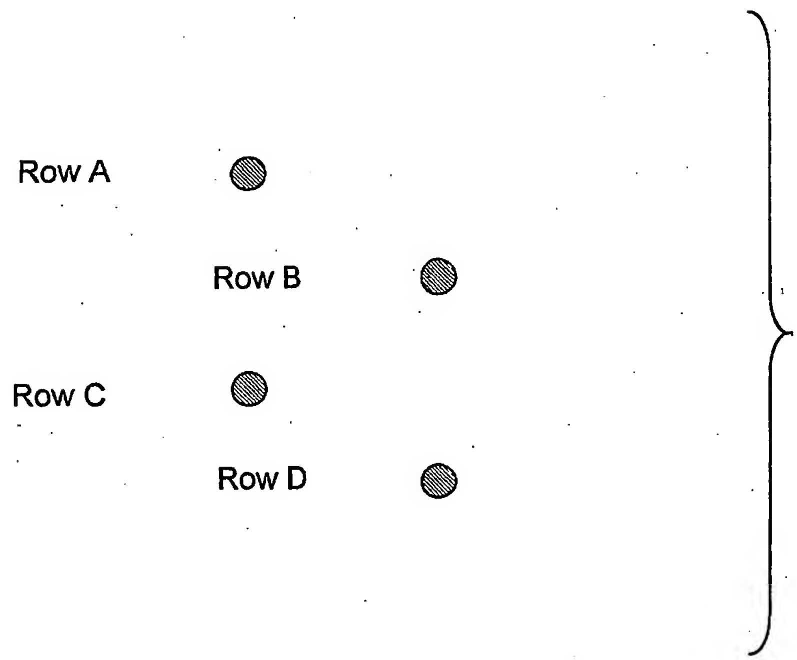


FIG. 71S

s1		s2		s269		s270	
	RGBa		RGBa		RGBc		RGBc
2	RGBb	2	RGBb	1072	RGBd	1072	RGBd
	RGBc		RGBc		RGBa		RGBa
4	RGBd	4	RGBd	1074	RGBb	1074	RGBb
	-----		RGBa		RGBc		RGBc
6	-----	6	RGBb	1076	RGBd	1076	RGBd
	-----		RGBc		-----		RGBa
8	-----	8	RGBd	1078	-----	1078	RGBb
	-----		-----		-----		RGBc
10	-----	10	-----	1080	-----	1080	RGBd
	72A		72B		72C		72D

FIGs. 72A-72D

Scan Pass s3 Time t1

Line	Dot	1		3		5
3	Xa	o	o	o	o	o
4		o	o	o	o	o
5		o	o	o	o	o
6		Xb	o	o	o	o
7		o	o	o	o	o
8		o	o	o	o	o
9	Xc	o	o	o	o	o
10		o	o	o	o	o
11		o	o	o	o	o
12		Xd	o	o	o	o
13		o	o	o	o	o

FIG. 74A

Scan Pass s3 Time t3

Line	1		3		5		7
3	Xa	o	o	o	o	o	o
4	o	o	o	o	o	o	o
5	o	o	o	o	o	o	o
6	Xb	Xb	Xb	o	o	o	o
7	o	o	o	o	o	o	o
8	o	o	o	o	o	o	o
9	Xc	o	o	o	o	o	o
10	o	o	o	o	o	o	o
11	o	o	o	o	o	o	o
12	Xd	Xd	Xd	o	o	o	o
13	o	o	o	o	o	o	o

FIG. 74B

Scan Pass s3 Time t1920

Line	1914		1916		1918		1920
3	Xa	Xa	Xa	Xa	Xa	o	o
4	o	o	o	o	o	o	o
5	o	o	o	o	o	o	o
6	Xb	Xb	Xb	Xb	Xb	Xb	Xb
7	o	o	o	o	o	o	o
8	o	o	o	o	o	o	o
9	Xc	Xc	Xc	Xc	Xc	o	o
10	o	o	o	o	o	o	o
11	o	o	o	o	o	o	o
12	Xd	Xd	Xd	Xd	Xd	Xd	Xd
13	o	o	o	o	o	o	o

FIG. 74C

Scan Pass s3 Time t1924

Line		1918		1920		1922		1924
3	Xa	Xa	Xa					
4	o	o	o					
5	o	o	o					
6	Xb	Xb	Xb		Xb			
7	o	o	o					
8	o	o	o					
9	Xc	Xc	Xc					
10		o	o	o				
11		o	o	o				
12		Xd	Xd	Xd		Xd		
13		o	o	o				

FIG. 74D

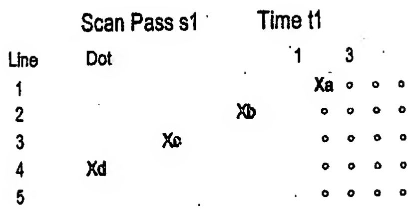


FIG. 73A

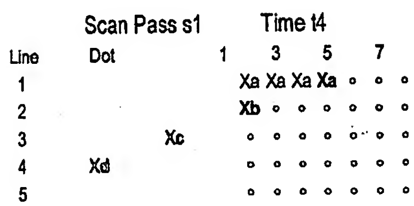


FIG. 73B

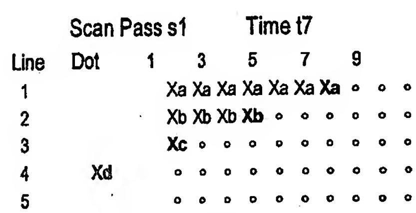


FIG. 73C

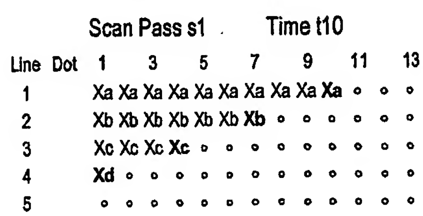


FIG. 73D

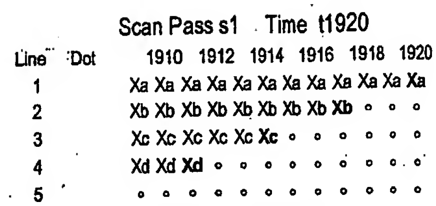


FIG. 73E

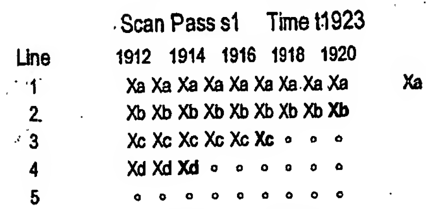


FIG. 73F

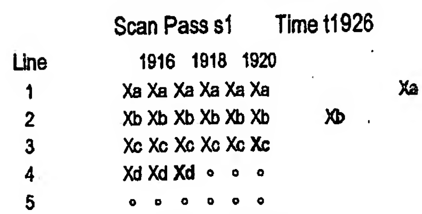


FIG. 73G

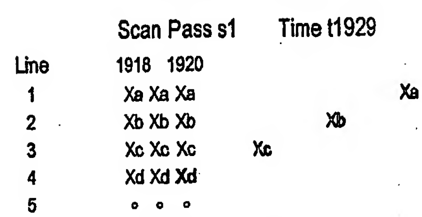


FIG. 73H

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference MAG-01PCT	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/US 01/27118	International filing date *(day/month/year)* 02/09/2001	(Earliest) Priority Date *(day/month/year)* 02/09/2001
Applicant MAGIC LANTERN, LLC.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).
4. With regard to the **title**,
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:
5. With regard to the **abstract**,
   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. 1
   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.
   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/27118

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N9/31

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 00 20912 A (ADVANCED LASER TECH ;CONEMAC DONALD C (US)) 13 April 2000 (2000-04-13) the whole document	1-85
X	US 6 137 461 A (FROST HOLGER ET AL) 24 October 2000 (2000-10-24) the whole document	1-85
X	US 6 154 259 A (FINK CHARLES G ET AL) 28 November 2000 (2000-11-28) abstract; figures 11-13,16-19,31 column 19, line 7 - line 14	1,34,56, 77
X	US 5 774 174 A (HARDIE ROBERT JOSEPH) 30 June 1998 (1998-06-30) abstract; figures 4,6,7A,7C,8	1,34,56, 77

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 September 2002	19/09/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Pigniez, T

2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/27118

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
E	WO 02 21850 A (MAGIC LANTERN LLC ;CALLISON JOHN P (US); PEASE JEFFREY S (US); PEA) 14 March 2002 (2002-03-14) the whole document ---	1-85
A	US 5 715 021 A (BESSLER ROGER FRANK ET AL) 3 February 1998 (1998-02-03) abstract; figures 1-3,8C,8D ---	1-85
A	WO 98 35504 A (KARAKAWA MASAYUKI ;LASER OPTICS RES CORP (US); MARTINSEN ROBERT J) 13 August 1998 (1998-08-13) abstract; figures 1,2,8 ---	1-85
A	US 4 297 723 A (WHITBY) 27 October 1981 (1981-10-27) abstract; figures 2-4 -----	1-85

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/27118

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 0020912	A	13-04-2000	US	6175440	B1	16-01-2001
			AU	6295199	A	26-04-2000
			BR	9914388	A	04-12-2001
			CN	1322307	T	14-11-2001
			EP	1119793	A1	01-08-2001
			NO	20011741	A	06-06-2001
			PL	347162	A1	25-03-2002
			TW	442667	B	23-06-2001
			WO	0020912	A1	13-04-2000
US 6137461	A	24-10-2000	DE	19726860	C1	28-01-1999
			AU	734127	B2	07-06-2001
			AU	6294498	A	04-01-1999
			BR	9804948	A	24-08-1999
			CA	2246554	A1	24-12-1998
			CN	1227032	T	25-08-1999
			DE	59804652	D1	08-08-2002
			WO	9859500	A1	30-12-1998
			EP	0925690	A1	30-06-1999
			JP	2000505275	T	25-04-2000
			RU	2151470	C1	20-06-2000
			TW	424395	B	01-03-2001
			ZA	9802411	A	30-09-1998
US 6154259	A	28-11-2000	NONE			
US 5774174	A	30-06-1998	CA	2196625	A1	08-08-1997
WO 0221850	A	14-03-2002	AU	8696101	A	22-03-2002
			WO	0221850	A2	14-03-2002
US 5715021	A	03-02-1998	AU	6131294	A	29-08-1994
			CA	2155310	A1	18-08-1994
			CN	1119482	A	27-03-1996
			DE	69427860	D1	06-09-2001
			DE	69427860	T2	11-04-2002
			EP	0704138	A1	03-04-1996
			EP	0884914	A1	16-12-1998
			JP	8509067	T	24-09-1996
			WO	9418802	A1	18-08-1994
			US	5614961	A	25-03-1997
			US	5920361	A	06-07-1999
WO 9835504	A	13-08-1998	AU	722995	B2	17-08-2000
			AU	6137098	A	26-08-1998
			EP	0956707	A1	17-11-1999
			JP	2000514274	T	24-10-2000
			WO	9835504	A1	13-08-1998
US 4297723	A	27-10-1981	NONE			

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

FORWARDS
FEE EARNER: AJC DEADLINE(S): 3.1.03

PCT

To:

CHETTLE, Adrian John et al
WITHERS & ROGERS
Goldings House
2 Hays Lane
London SE1 2HW
GRANDE BRETAGNE

RECEIVED ... 2002

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing (*day/month/year*) 03.12.2002

Applicant's or agent's file reference
P706899PCT/AJC

IMPORTANT NOTIFICATION

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US01/27118	02/09/2001	02/09/2000

Applicant
MAGIC LANTERN, LLC.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. REMINDER

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

For the purpose of deciding whether the claimed invention is patentable or not, the elected Offices may apply criteria additional to or different from the criteria on which the international preliminary examination report is based (see Articles 27(5), 33(5)). Additional criteria may include e.g. exemptions from patentability and the requirements of enabling disclosure and of clarity and support of claims.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Eriksson, I Tel.+49 89 2399-2432

Form PCT/IPEA/416 (July 1992)

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P706899PCT/AJC	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/US01/27118	International filing date *(day/month/year)* 02/09/2001	Priority date *(day/month/year)* 02/09/2000
International Patent Classification (IPC) or national classification and IPC H04N9/31		
Applicant MAGIC LANTERN, LLC.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 5 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
02/04/2002	03.12.2002
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Zanella, C Telephone No. +49 89 2399 8960

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/US01/2711[illegible]

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, pages:

1-110	as originally filed			

Claims, No.:

1-29	as received on	13/05/2002	with letter of	10/05/2002

Drawings, sheets:

1/58-58/58	as originally filed			

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☒ the claims, Nos.: 1-86

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	2-17,19-29
	No:	Claims	1,18
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-29
Industrial applicability (IA)	Yes:	Claims	1-29
	No:	Claims	

2. Citations and explanations
see separate sheet

ITEM V

Reference is made to the following documents:

D1: US-A-6 137 461 (FROST HOLGER ET AL) 24 October 2000 (2000-10-24)

D2: US-A-6 154 259 (FINK CHARLES G ET AL) 28 November 2000 (2000-11-28)

D3: US-A-4 297 723 (WHITBY) 27 October 1981 (1981-10-27)

It is noted that document D1 discloses (see fig. 1) :
a system for projecting an image frame onto a viewing surface (43) by the illumination of more frames, each frame comprising an array of potential dot locations on such viewing surface which are substantially illuminated during a frame pass for such frame (see dot locations in fig. 2), comprising:
a scanner (see mirrors 41 and 42) adapted to direct two light beams onto the viewing surface (43) to form a desired pattern of spots (two, see fig. 2) on such viewing surface, wherein at the same time during such frame pass one spot (39) of such pattern of spots is spaced more than one dot location (spaced mp and mz) from the other spot (39') of the pattern of spots;
said scanner being further adapted to traverse the directed light beams such that the spots of the pattern of spots are swept along two separate lines of dot locations (see separate lines in fig. 2) of such array of dot locations during each of a succession of scan passes during such frame pass.
The subject-matter of claim 1 lacks therefore novelty (Art. 33(2) PCT).

It is further noted that the subject- matter of claim 1 also lacks at least an inventive step having regard to the disclosures of documents D2 and D3, since these documents disclose systems where frame scanning by means of a plurality of spots is performed, and where the spots are spaced more than one dot location-, see respectively fig. 16-29 and fig. 3.

The above objections of lack of novelty and inventive step also directly apply to the subject-matter of independent claim 18, directed to a "method" and including "method steps" corresponding to performing each operation carried out by the means

of claim 1. Also the subject-matter of claim 18 therefore lacks novelty.

The subject-matter of the remaining dependent claims 2-17,19-29 only appears to relate to routine details of the person skilled in the art working in the field of image projection; some of these details are for example disclosed by the above documents, see use of fibres (documents D1 and D2), of optical couplers, of focusing optics etc...

The subject-matter of claims 2-17,19-29 therefore lacks an inventive step (Art 33(3) PCT).

The presently claimed subject-matter relates to the field of electronics and in particular to the design of electronic devices which are then manufactured by the industry. The present claims possess thus industrial applicability.

CLAIMS:

1. A system (10) for projecting an image onto a viewing surface (12) by the illumination of one or more frames, each frame comprising an array of potential dot locations on such viewing surface which are substantially illuminated during a frame pass for such frame, comprising:

a scanner (70) adapted to direct two or more light beams onto the viewing surface (12) to form a desired pattern of two or more spots on such viewing surface, wherein at substantially the same time during such frame pass one or more spots of such pattern of spots is spaced more than one dot location of such array of dot locations from any other spot of the pattern of spots;

said scanner (70) being further adapted to traverse the directed light beams such that the spots of the pattern of spots are swept along two or more substantially separate lines of dot locations of such array of dot locations during each of a succession of two or more scan passes during such frame pass.

2. The system of claim 1 further comprising:

two or more optical fibers (42), each optical fiber adapted to emit one or more of the light beams from an emitting end thereof to form one or more spots of the pattern of spots.

3. The system of claim 1 or 2, and further comprising one or more fiber-based beam couplers (29) for dividing one or more of such light beams into two or more light beams.

4. The system of claim 1, 2 or 3, and further comprising one or more fiber-based beam couplers (29) for combining two or more of the light beams into one optical fiber.

5. The system of any preceding claim and further comprising a single focusing optic (60) positioned to focus two or more of said light beams simultaneously.

6. The system of any preceding claim wherein said scanner (70) is adapted to form a pattern of three or more spots.

7. The system of any preceding claim and adapted so to position said light beams with respect to each other such that the pattern of spots on said viewing surface is two-dimensional.

8. The system of any preceding claim wherein said scanner is further adapted such that during a frame pass, one or more spots scanned to illuminate one or more lines of dot locations during one scan pass of such frame pass is not scanned to illuminate any line of dot locations adjacent to such one line of dot locations during any other scan pass of such frame pass.

9. The system of any preceding claim wherein said scanner (70) is a raster scanner.

10. The system of any preceding claim and adapted so that said scanner substantially continuously adjusts the position of the pattern of spots in a direction transverse of the scan path between the initiation of successive scan passes.

11. The system of any preceding claim and adapted so that two or more of the light beams are of substantially different wavelengths.

12. The system of any preceding claim and adapted so that one or more light beams directed to the viewing surface (12) is one or more combined light beams.

13. The system of claim 12 wherein, in use, one or more of said combined beams is a combination of two or more light beams having substantially the same wavelength.

14. The system of claim 12 or 13 wherein, in use, one or more of said combined beams is a combination of two or more light beams having substantially different wavelengths.

15. The system of claim 12, 13 or 14 wherein, in use, one or more of said combined beams is a composite beam of three or more light beams having substantially different

wavelengths.

16. The system of claim 15 wherein, in use, said composite beam is a combination of three or more beams, each of a primary color.

17. The system of any preceding claim wherein said scanner is further adapted such that during one or more scan passes of a frame pass, one or more spots of the pattern of spots substantially overwrites one or more dot locations of a line of dot locations swept by another of said spots of the pattern of spots during the same or another scan pass of such frame pass.

18. A method of projecting an image onto a viewing surface by the illumination of one or more frames, each frame comprising an array of potential dot locations on such viewing surface illuminated during a frame pass for such frame, comprising the steps of:

forming a desired pattern of two or more spots on such viewing surface wherein at substantially the same time during such frame pass one or more spots of such pattern of spots is spaced more than one dot location of such array of dot locations from any other spot of the pattern of spots;

sweeping such desired pattern of spots in a line direction along two or more different lines of desired dot locations of said array on the viewing surface during a scan pass;

adjusting the position of the pattern of spots on the viewing surface in a direction transverse of the line direction; and

repeating the sweeping and adjusting steps a desired number of times to project a frame of such image during such frame passes.

19. The method of claim 18 wherein the desired pattern of spots is two-dimensional.

20. The method of claim 18 or claim 19 wherein during each of one or more frame passes each of one or more spots of the desired pattern of spots scanned to illuminate a

line of dot locations during a sweeping step is not scanned to illuminate any other line of dot locations adjacent to said line of dot locations during any other sweeping step.

21. The method of any of claims 18-20 wherein said desired pattern of spots includes three or more spots.

22. The method of any of claims 18-21 and further comprising the steps of:

conducting one or more light beams through one or more optical fibers;

splitting one or more of said conducted light beams with one or more fiber-based beam splitters into two or more light beams.

23. The method of any of claims 18-22 and further comprising the steps of:

conducting one or more light beams through one or more optical fibres;

emitting one or more of the light beams from each of two or more emitting ends of separate optical fibres; and

directing the light beams emitted from the emitting ends of said optical fibres in the emitting step to the viewing surface to form spots of said pattern of spots.

24. The method of claim 23 further comprising the step of:

splitting one or more of such conducted light beams into two or more light beams conducted through one or more optical fibers.

25. The method of any of claims 18-24 wherein the illuminating step further comprises the steps of:

combining two or more light beams into one or more optical fibers with one or more fiber-based beam combiners to form one or more combined beams;

emitting said one or more combined beams from the emitting end of one or more respective optical fibers; and

directing said one or more combined beams to the viewing surface to form one or more combined spots as a spot of the desired pattern of spots on the viewing surface.

26. The method of claim 25 wherein :

said combining step further includes combining one or more of said combined beams with one or more other of said light beams and/or one or more other of said combined light beams to form one or more composite beams;

said emitting step includes emitting said composite light beam from the emitting end of one or more respective optical fibres; and

said directing step includes directing the composite light beam to the viewing surface to form one or more composite spots as one or more spots of the desired pattern of spots on the viewing surface.

27. The method of any of claims 18-26 wherein said adjusting step is substantially continuous during substantially all sweeping steps of a frame pass.

28. The method of any of claims 18-27 wherein during one or more sweeping steps of a frame pass one or more of the spots of the desired pattern of spots substantially overwrites one or more dot location of a line of dot locations swept by another of said spots of the desired pattern of spots during the same or another sweeping step.

29. The method of any of claims 19-28 wherein the illuminating step still further comprises the step of:

focusing the emitted light beams simultaneously with a single focusing optic.